829

USGS-OFR-82-973

USGS-OFR-82-973

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PRELIMINARY INTERPRETATION OF THERMAL DATA FROM THE NEVADA TEST SITE

Open-File Report 82-973

1982

Prepared by the U.S. Geological Survey

for the

Nevada Operations Office
U.S. Department of Energy
(Interagency Agreement DE-AI08-78ET44802)

USGS-OFR-82-973

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PRELIMINARY INTERPRETATION OF THERMAL DATA FROM THE NEVADA TEST SITE

by

J. H. Sass and Arthur H. Lachenbruch

Open-File Report 82-973

1982

Abstract

Analysis of data from 60 wells in and around the Nevada Test Site, including 16 in the Yucca Mountain area, indicates a thermal regime characterized by large vertical and lateral gradients in heat flow. Estimates of heat flow indicate considerable variation on both regional and local scales. The variations are attributable primarily to hydrologic processes involving interbasin flow with a vertical component of (seepage) velocity (volume flux) of a few mm/yr. Apart from indicating a general downward movement of water at a few mm/yr, the results from Yucca Mountain are as yet inconclusive.

INTRODUCTION

The Geothermal Studies Project, USGS, has been periodically measuring temperatures in holes drilled in and near the Nevada Test Site (NTS) in southern Nevada (fig. 1). Our primary motivation has been the measurement of the earth's heat flow. Thus, when we examined temperature profiles within the context of heat flow in the western United States (Sass and others, 1971), we discarded most of the data we had obtained as unsuitable owing to hydrologic disturbances to the conductive heat-flow field. Recently (Lachenbruch and Sass, 1977), we have attempted to refine our interpretation of the variation of heat flow in the western U.S. In particular, we have sought to explain much of the scatter in heat flow within the Great Basin in terms of local water circulation. In addition, we have interpreted the large area of anomalously low heat flow (Eureka Low, EL, fig. 1) as reflecting regional water flow with a downward (seepage) velocity component on the order of a few mm/y (Lachenbruch and Sass, 1977) consistent with regional hydrologic studies (see Winograd and Thordarson, 1975). The regional heat flow from beneath the zone of hydrologic disturbance in the Eureka Low may be the same as that characteristic of the Great Basin in general (~80 mWm^{-2}, or ~2 HFU) or it could be as high as ~100 mWm^{-2} (~2.5 HFU).

In view of the importance of hydrologic processes in determining the suitability of proposed repository sites, and because thermal measurements are extremely sensitive to these processes, we have re-examined our existing data and obtained additional data from Syncline Ridge near the Eleana Range, hole U15K in the Climax Stock, and from all available wells near Yucca Mountain (fig. 2). In this section, we briefly review the thermal data from approximately 60 wells and their implications for regional heat flow. We also examine in more detail the thermal data from the Yucca Mountain site and their implications for vertical water flow within and adjacent to the proposed nuclear waste repository.

Acknowledgments. Temperature measurements were made by Gordon Greene, Fred Grubb, Tom Moses, Bob Munroe, and Gene Smith. Conductivities were measured by Bob Munroe and Gene Smith. We are grateful to W. E. Wilson and Rick Waddell for their helpful comments and suggestions.

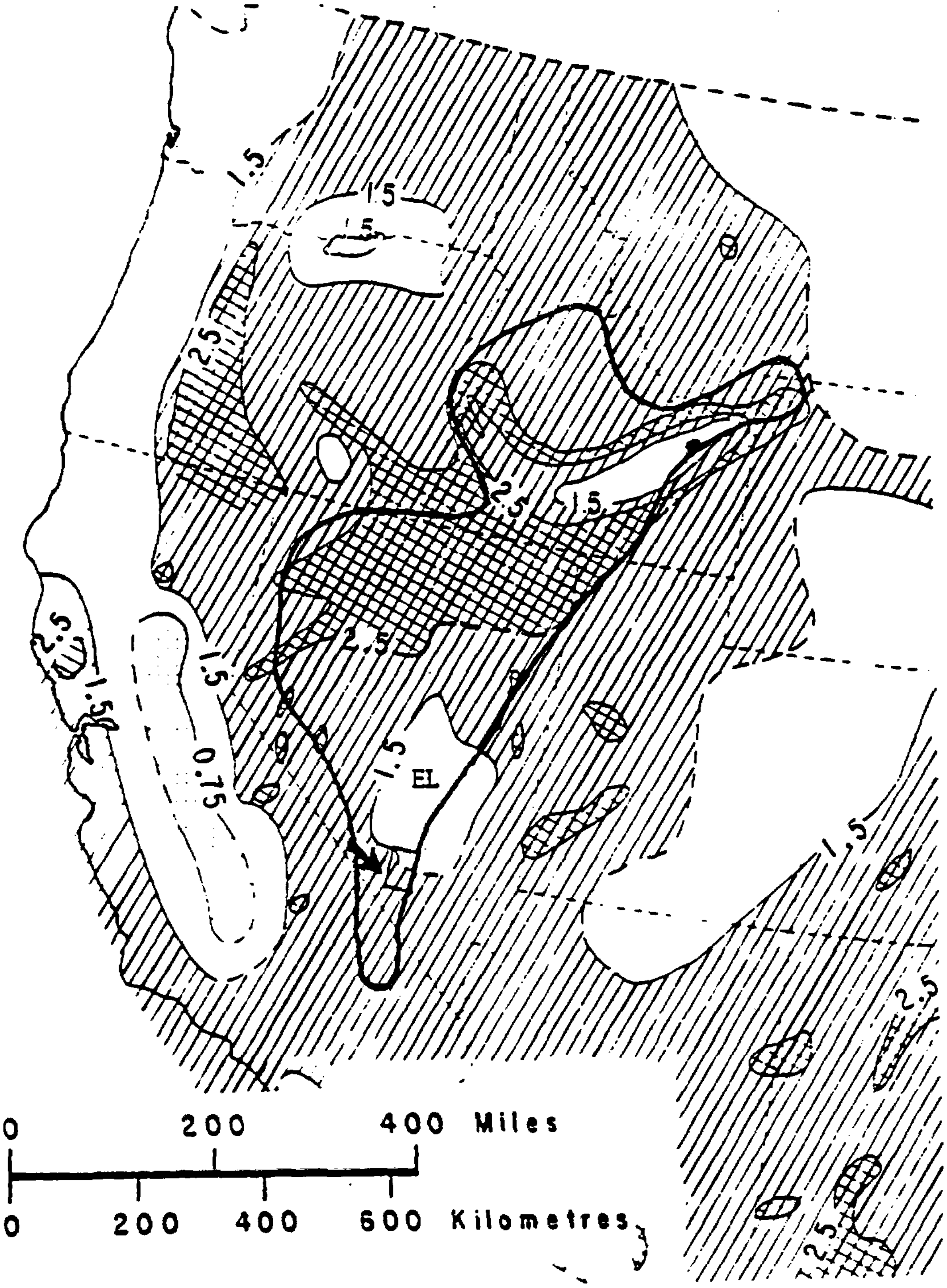

Figure 1. Map of western United States showing heat-flow contours (in HFU) 1 heat-flow unit (HFU) = 41.86 mW/m^{-2}. EL is Eureka Low. Arrow indicates outline of approximate boundaries of the Nevada Test Site (NTS). Heavy line is 2.5 HFU contour, based on the empirical relation between silica temperatures and heat flow (Swanberg and Morgan, 1978).

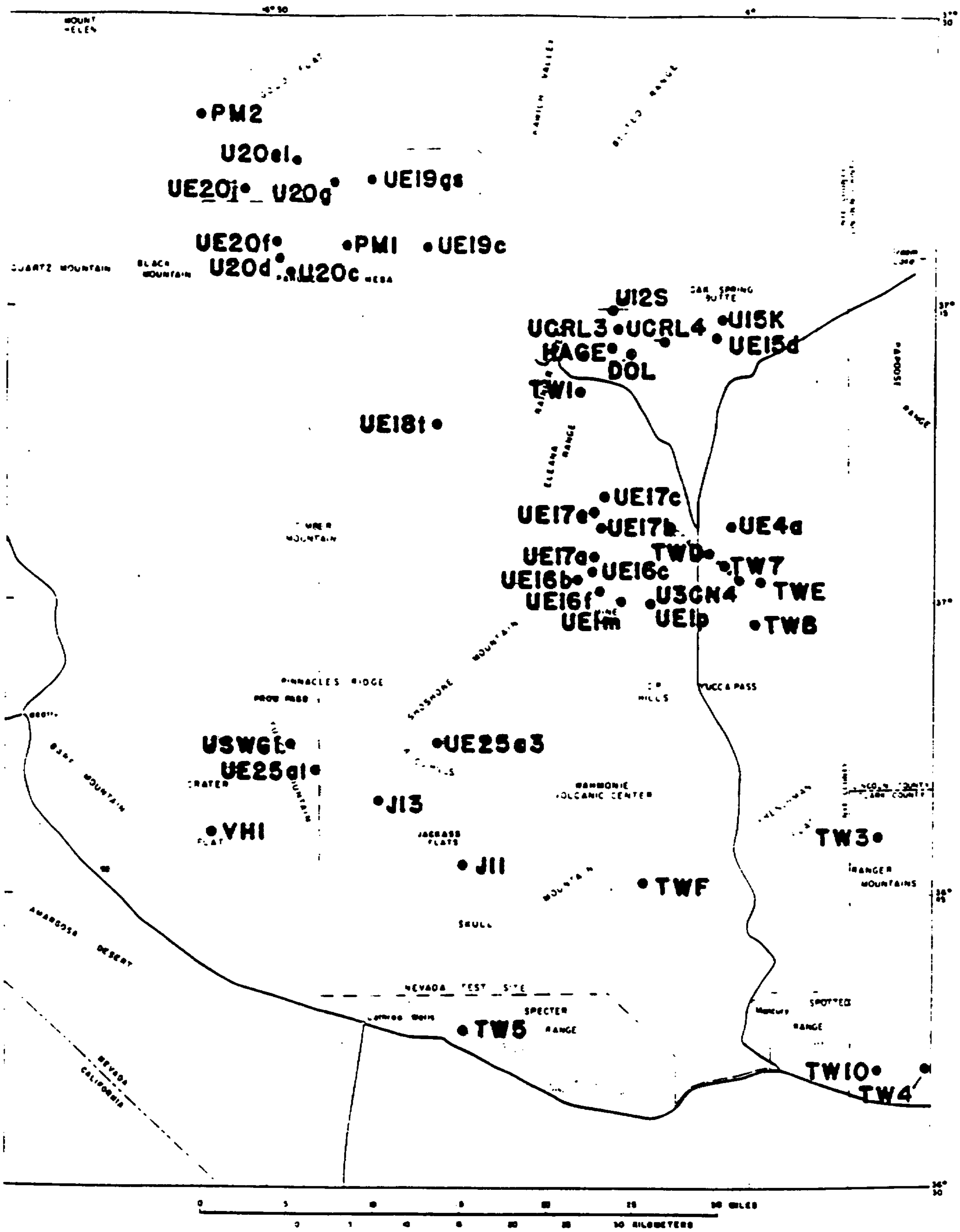

Figure 2. Map of the test-site region showing locations of wells discussed in the text.

REGIONAL HEAT FLOW

Available heat-flow data from the NTS region are summarized in table 1 and figure 3. The data described as "USGS unpublished" are preliminary and are subject to minor revision (± a few percent) upon further study. The data (fig. 3) indicate a typical Basin-and-Range distribution of heat flow in the region immediately surrounding Mercury but a rather complex situation to the north and west. The complexity of the thermal regime is further demonstrated, and can be explained to some extent, by consideration of all temperature data within the region (fig. 2). These data are presented as a series of composite temperature-depth plots ("worm diagrams") for different areas within the region in figures 4 through 8 and 10.

Beneath Pahute Mesa (fig. 4), temperature gradients are fairly low (~20 to 25°C/km), and the tuffs within which the wells were drilled have low thermal conductivities (1 to 1.5 $Wm^{-1} K^{-1}$) resulting in anomalously low values of regional heat flow. The deepest log we obtained from NTS was that in Ue20f (fig. 4). In the upper 1.5 km, the temperature gradient is 26°C/km and the calculated conductive heat flow is less than 40 mWm^{-2}. Below 1.5 km, there is a zone extending to nearly 3 km that is probably disturbed by a complex combination of lateral and vertical water flow. Below 3 km, the temperature profile is linear, and the gradient is 37°C/km. Thermal conductivities in this section are not well characterized, but reasonable values would result in heat-flow values between 80 and 100 mWm^{-2} which is typical of the Basin and Range Province in general. The implication here is that water is carrying off much of the earth's heat in the upper 3 km and delivering it elsewhere. Well PM-2 is a possible exception. Its temperature profile (fig. 4) might indicate regional heat flow or possibly just a local upwelling of convecting water.

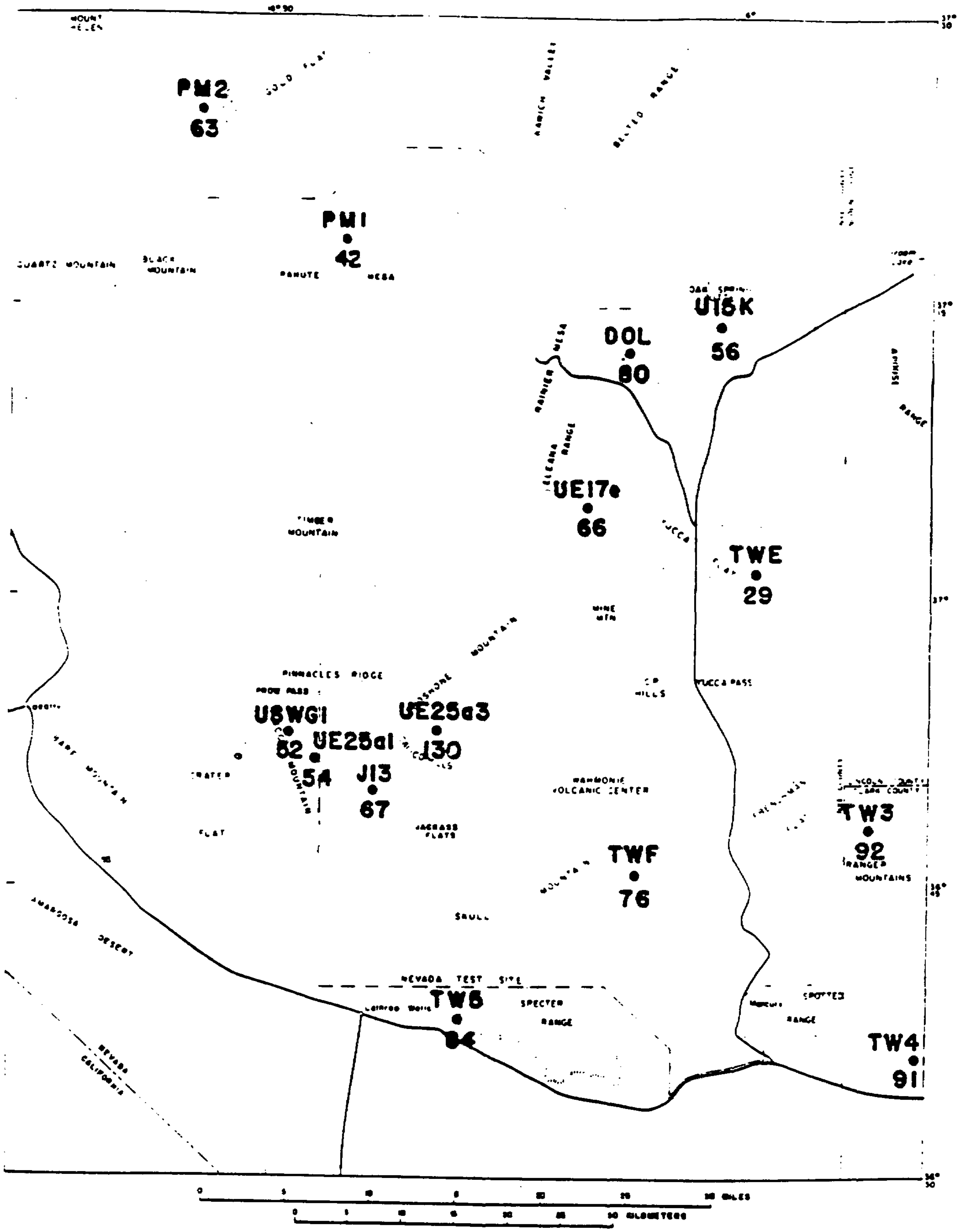

Figure 8. Regional heat-flow values within and adjacent to the Nevada Test Site.

TABLE 1. Heat-flow determinations in and adjacent to the Nevada Test Site (see Figures 2 and 3 for locations)

Well	Heat flow mWm^{-2}	Heat flow HFU	Reference
PM2	63	1.5	Sass and others, 1971
PM1	42	1.0	Sass and others, 1971
DOL	80	1.9	Sass and others, 1971
U15K	56	1.3	USGS unpublished
Ue17e	66	1.58	USGS unpublished
TWE	29	0.7	Sass and others, 1971
J-13	67	1.6	Sass and others, 1971
Ue25a1	54	1.3	Sass and others, 1980
Ue25b1	47	1.1	USGS unpublished
Ue25a3	130	3.1	Sass and others, 1980
USWG1*	52	1.25	Table 2, this paper
TWF	76	1.81	Sass and others, 1971
TW3	92	2.2	Sass and others, 1971
TW5	84	2.0	Sass and others, 1971
TW4	91	2.2	Sass and others, 1971

*Average heat flow in lowermost ~600 m.

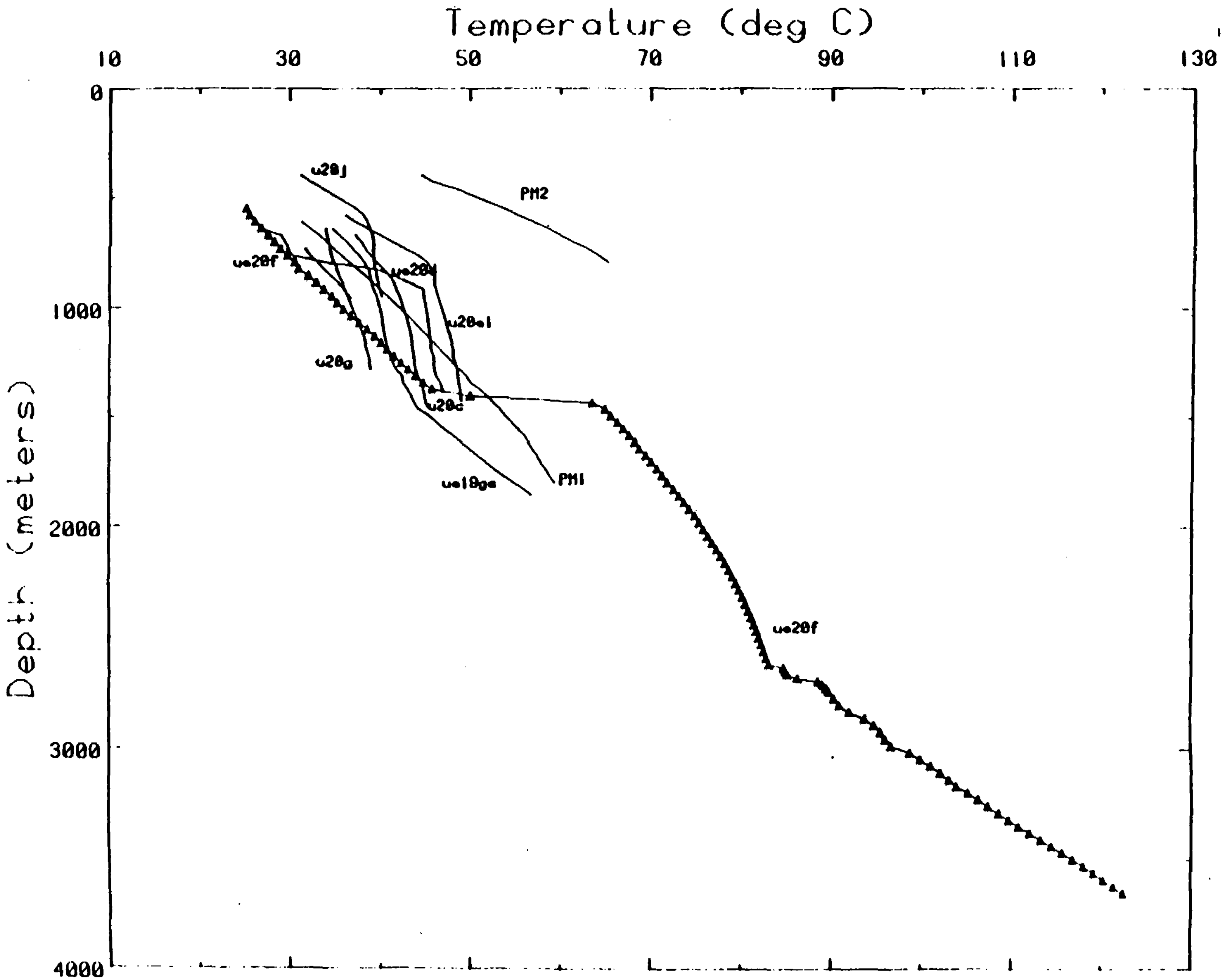

Figure 4. Composite Temperature Profile, Pahute Mesa

Consideration of temperatures from other areas of the NTS (figs. 5 through 8) also suggests lateral variations in heat flow that can be attributed largely to lateral and vertical water movement with vertical seepage velocities probably on the order of 1-10 mm/y.

The most reliable "flux plates" for determination of regional heat flow generally have been granitic bodies. Unfortunately, we have only one such determination (U15k, fig. 3), and even it is uncertain because the hole is relatively shallow (~260 m), and we have only one determination of thermal conductivity. The best documented heat-flux value in this region is that for UE17e (figs. 3 and 7) which was drilled in argillites of the Eleana Formation. This is the <u>only</u> well in this entire study for which we can rule out vertical water movement in the hole, as the access casing was completely grouted in. In other wells, some or all of the perturbations to the steady-state conductive thermal regime may be the result of water movement in the annulus between casing and borehole wall rather than water movement in the formation. Fortunately, however, it is usually possible to distinguish between the two types of flow on the basis of the shape of the disturbed temperature profile.

To characterize adequately the heat flow in this region, we require several holes to depths of several hundred meters, preferably drilled in granitic rocks, and with the annulus between access casing and borehole wall completely sealed off by grout or a similar medium.

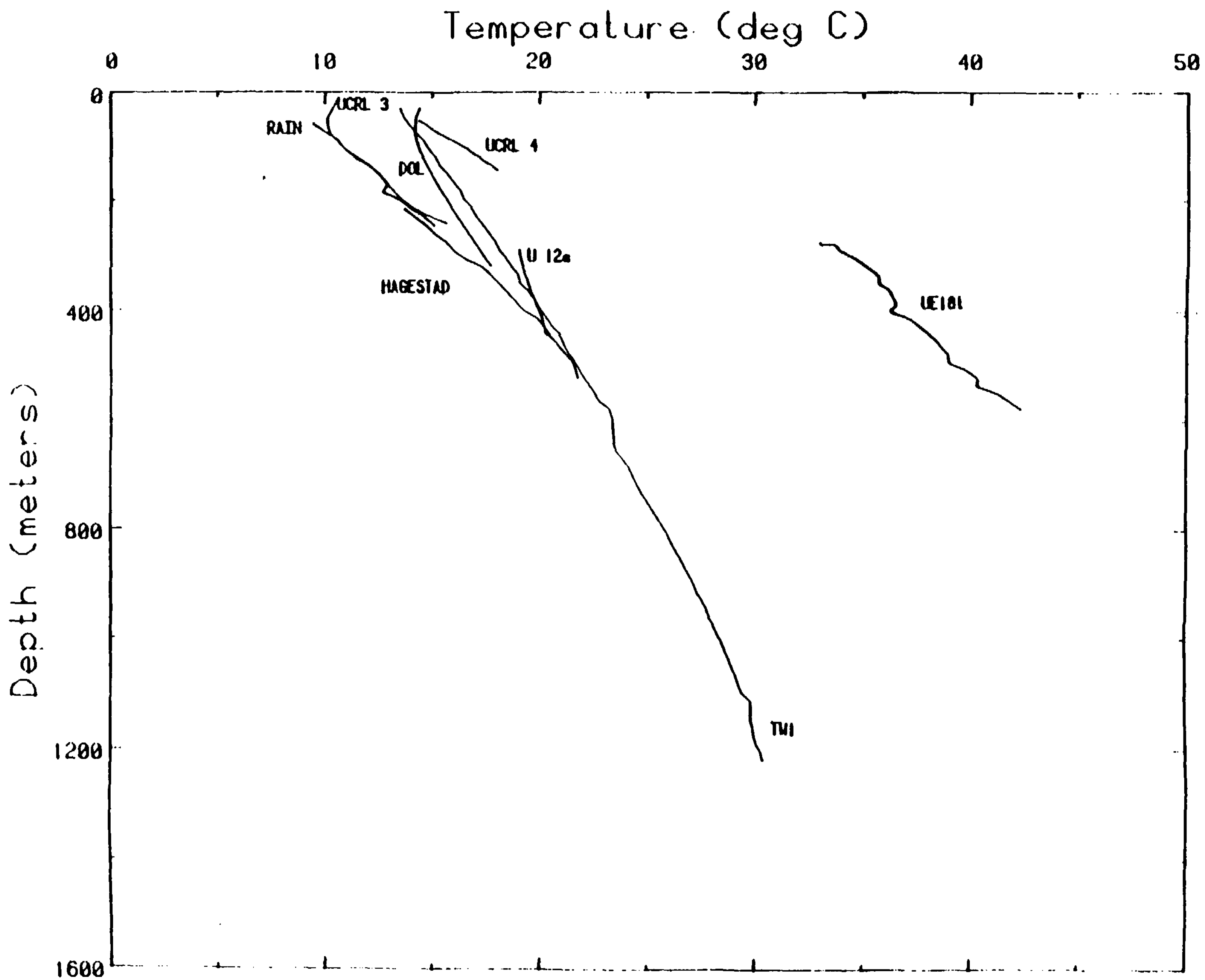

Figure 5. Composite Temperature Profile for Rainier Mesa & Environs.

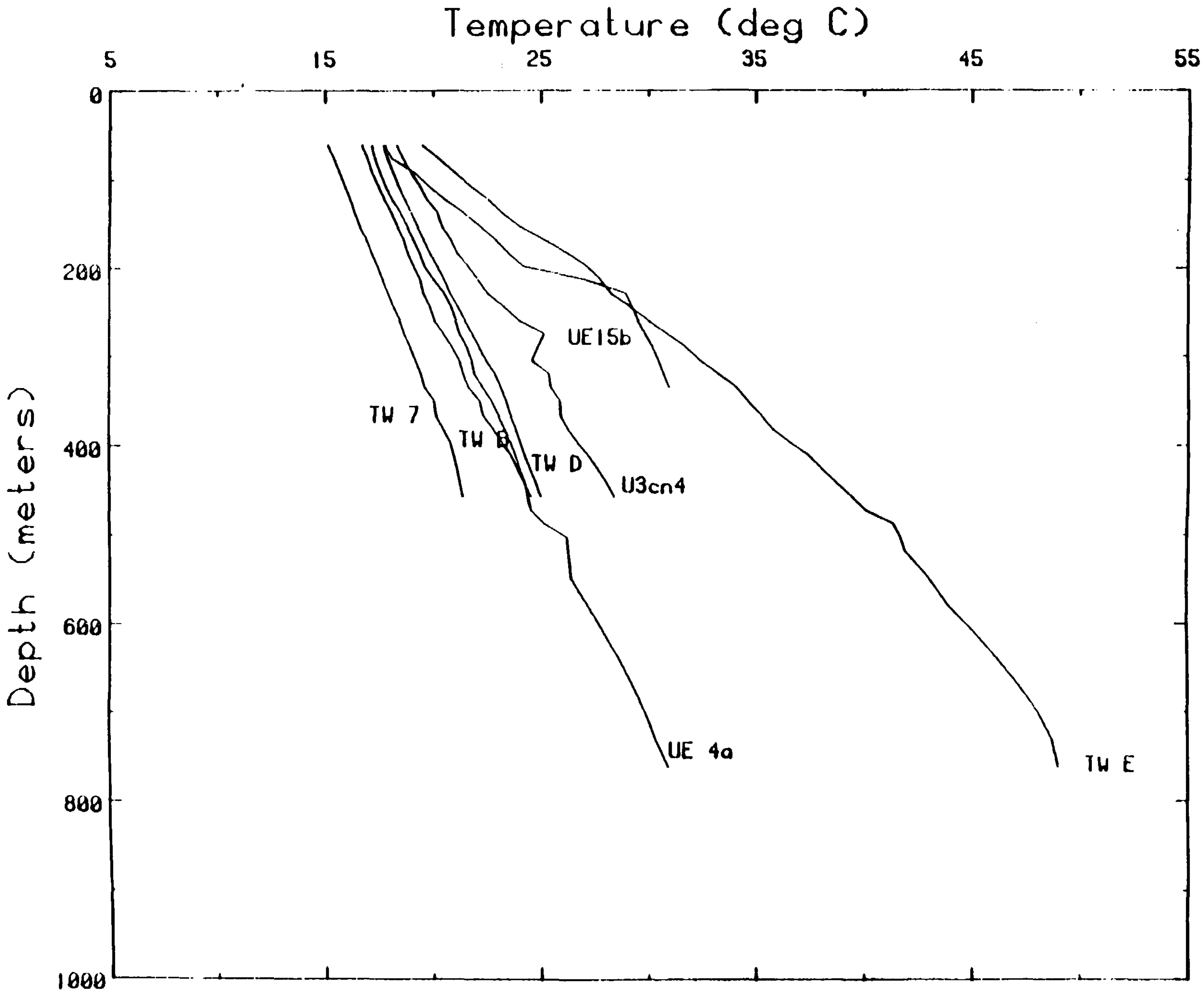

Figure 6. Composite Temperature Profile for Yucca Flat Area

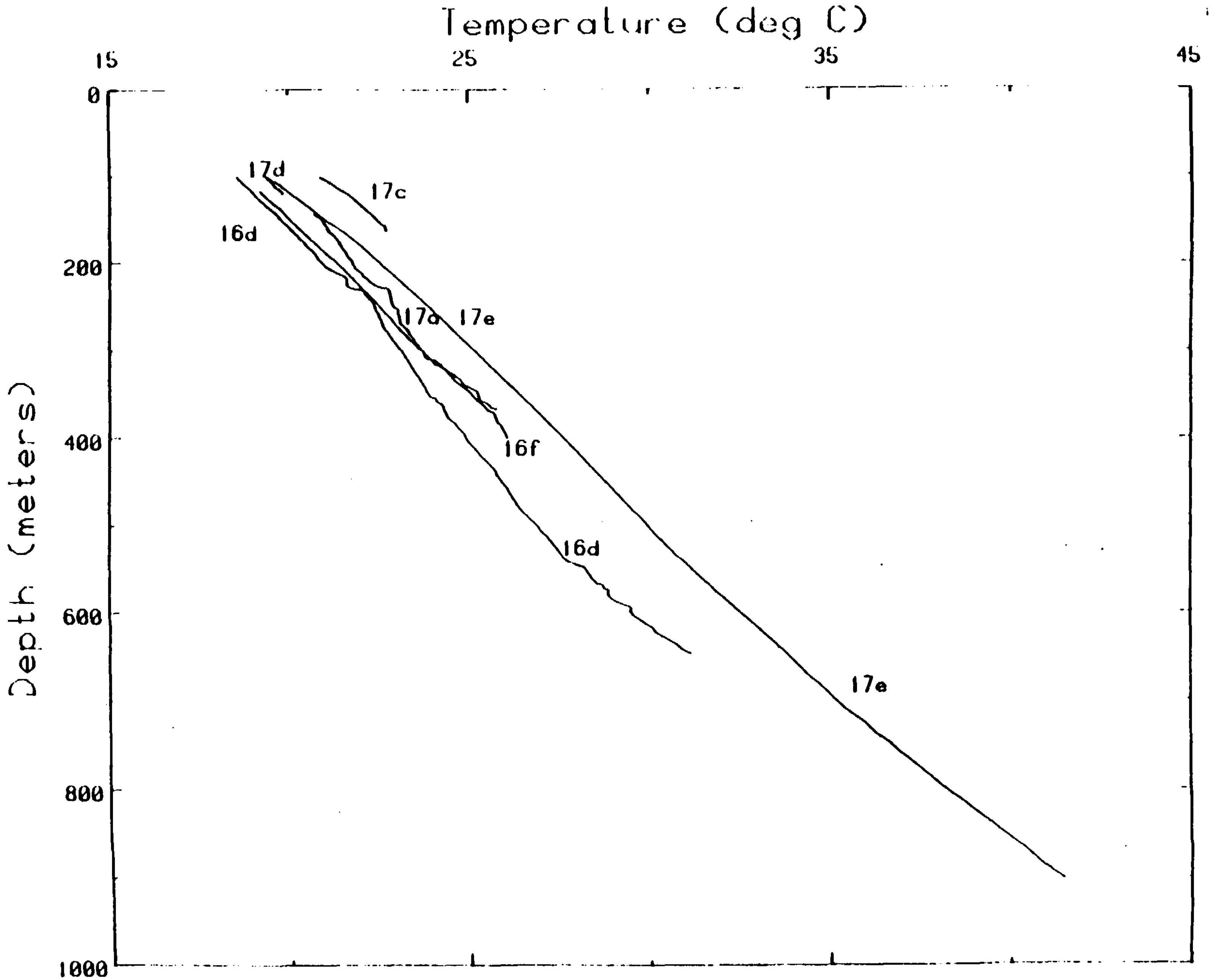

Figure 7. Composite Plot of Temperatures below 100 m, Syncline Ridge Area

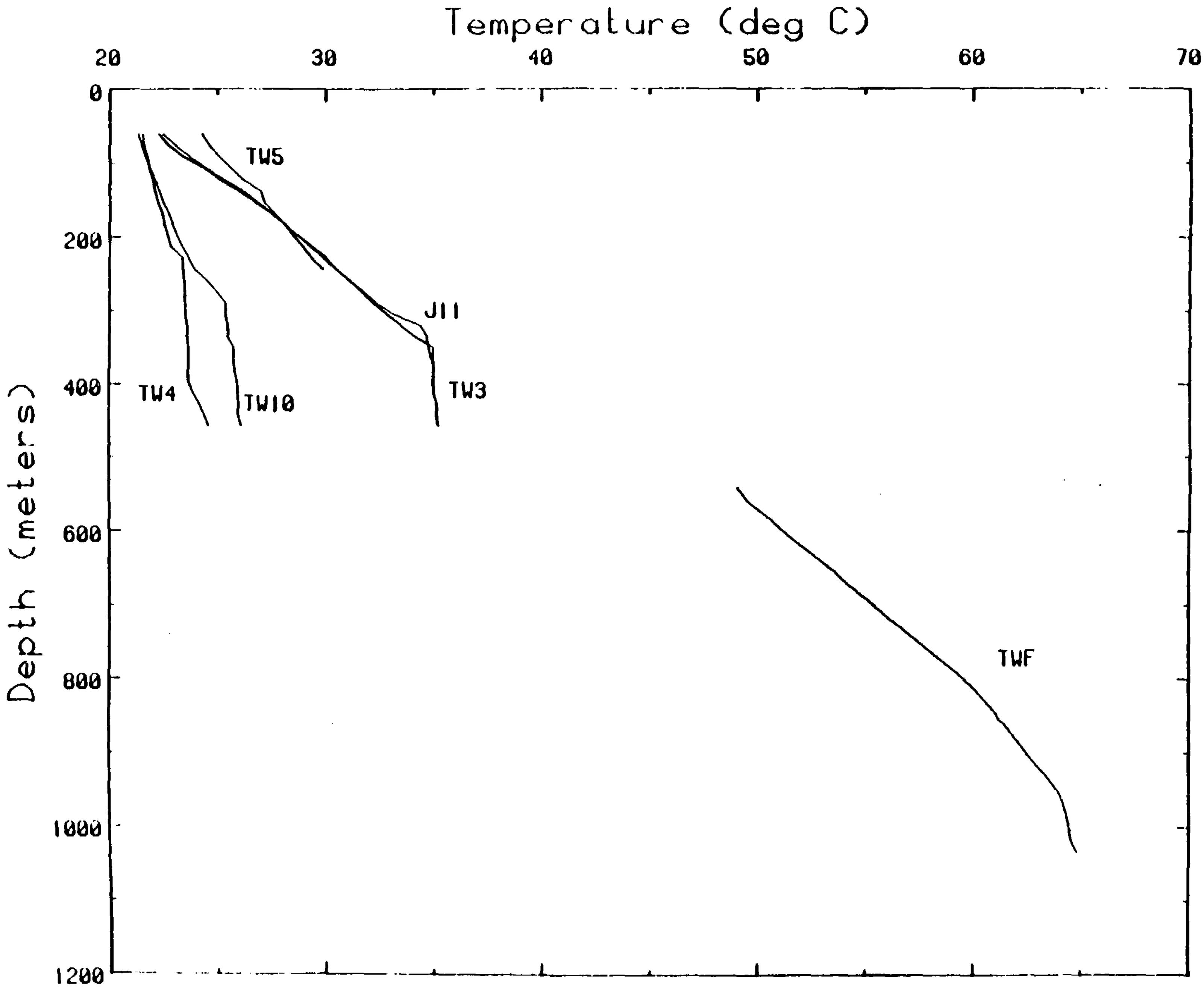

Figure 8. Composite Temperature Profile for the Southern NTS.

THERMAL REGIME OF YUCCA MOUNTAIN

Locations of wells drilled specifically to study the repository site being investigated at Yucca Mountain are shown in figure 9. The most recent temperature profiles from these wells (and some nearby wells, fig. 2) are presented in figures 10 and 11. The hydraulic potentiometric surface beneath Yucca Mountain is deeper than 500 meters. The curves show variations in thermal gradients to about 1,000 m. Thus, hydrologic disturbances to the temperature field may occur both above and below the water table. Some of the extreme variations in thermal gradient above the water table might be explained in terms of two-phase water flow, with the ratio of liquid to vapor varying as a function of depth (see Lachenbruch, 1981). At present, this seems to be the most reasonable physical explanation for the types of variations, both lateral and vertical, in temperature gradients observed in the "conductor holes" (UE25a4, 5, 6, and 7, fig. 9), a closely grouped series of holes drilled entirely within the unsaturated zone. Some, but by no means all, of the variations in gradient for this series (fig. 11) may be explained by long-lived transients resulting from the loss of large quantities of mud during drilling. The holes are, however, effectively in thermal equilibrium, and the gradient variations cannot be ascribed plausibly to variations in thermal conductivity (particularly where there are temperature reversals).

For the deepest wells (G1 and H1, fig. 10), systematic variations in temperature gradient occur without corresponding variations in thermal conductivity. Our preliminary interpretation suggested a systematic downward percolation of ground water through both unsaturated and saturated zones with seepage velocities of a few mm/y. With sufficient thermal conductivity data now available, we are able to test that interpretation quantitatively.

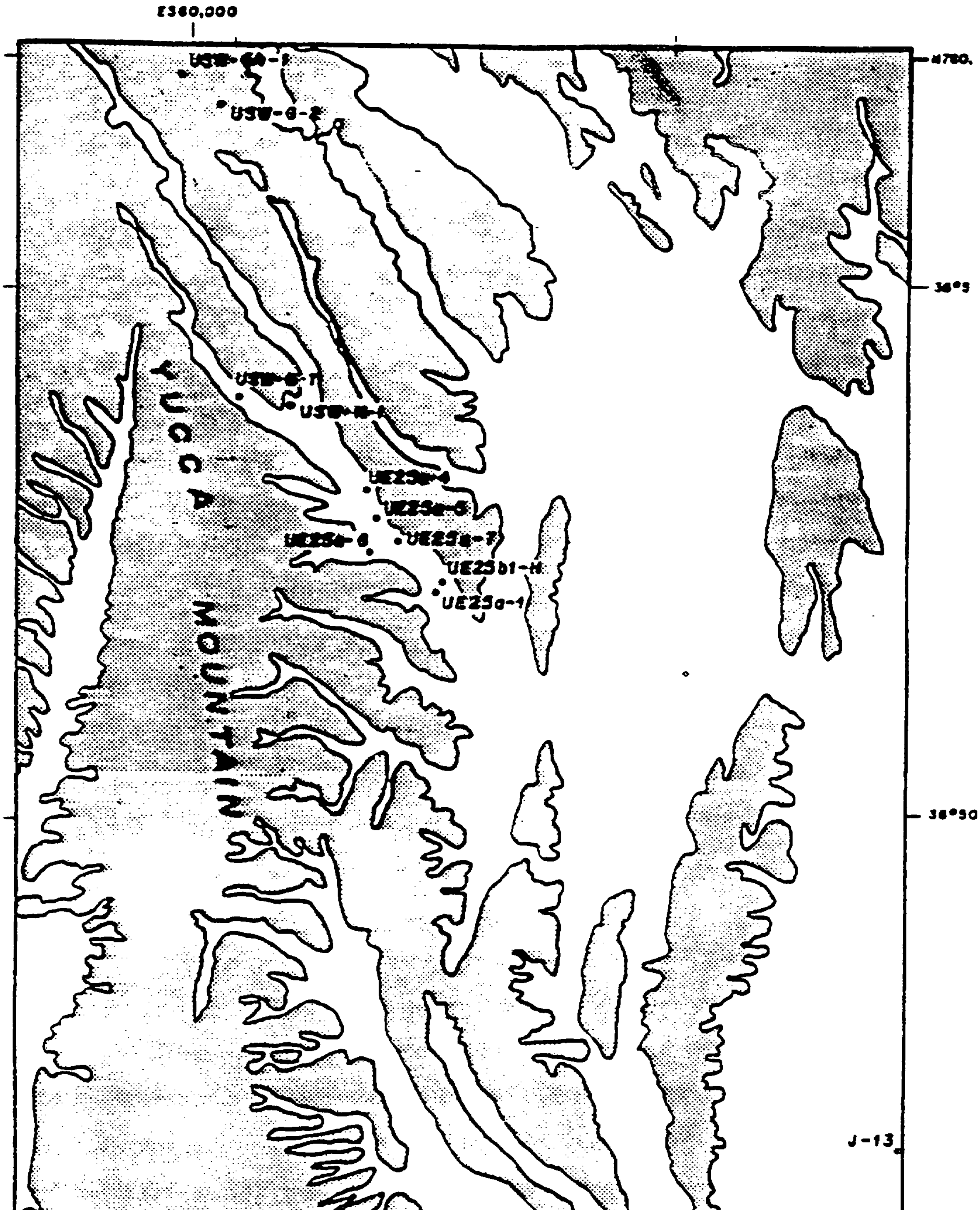

Figure 9. Locations of drill holes near Yucca Mountain.

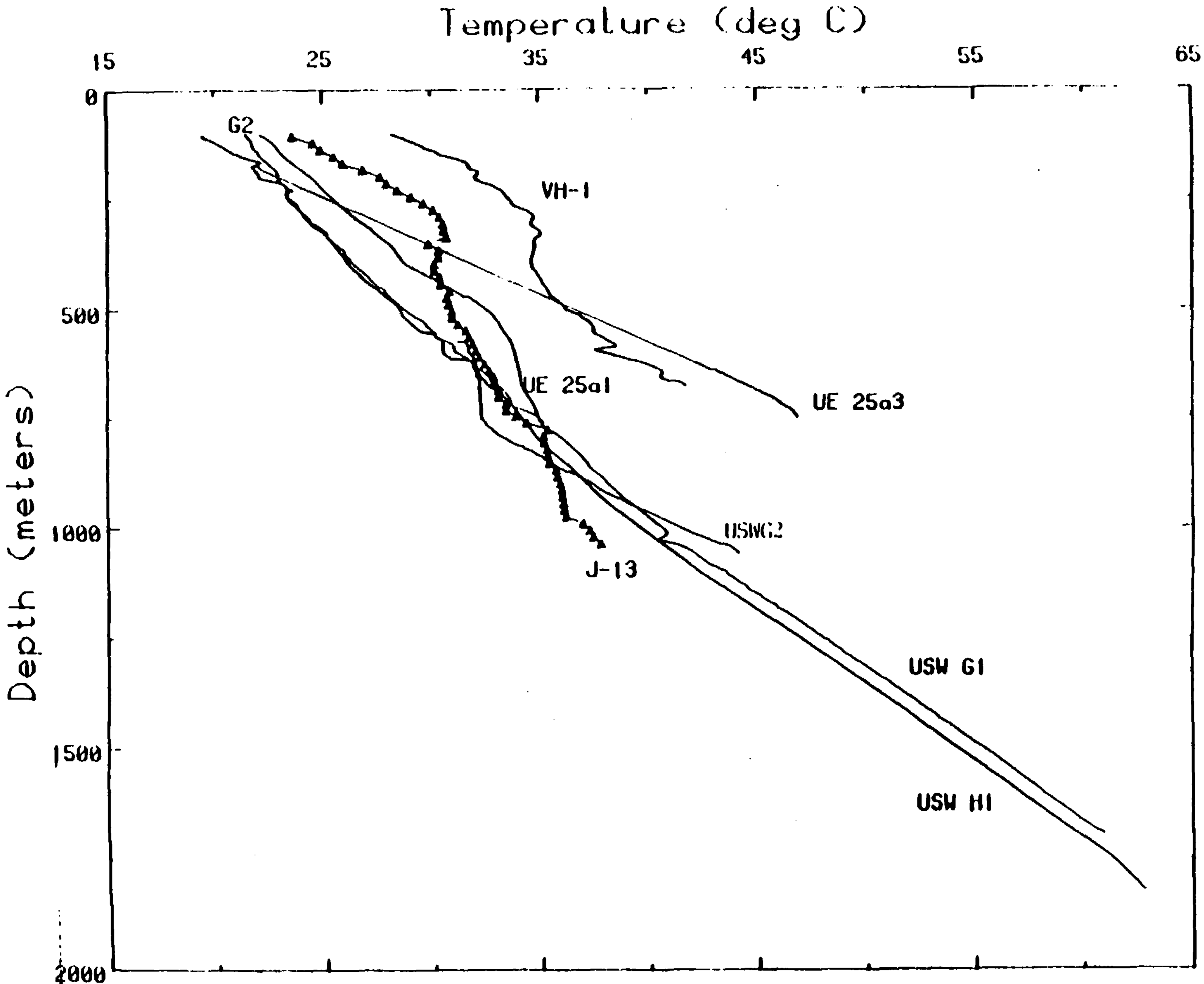

Figure 10. Temperatures in Wells deeper than 600 m, Yucca Mountain

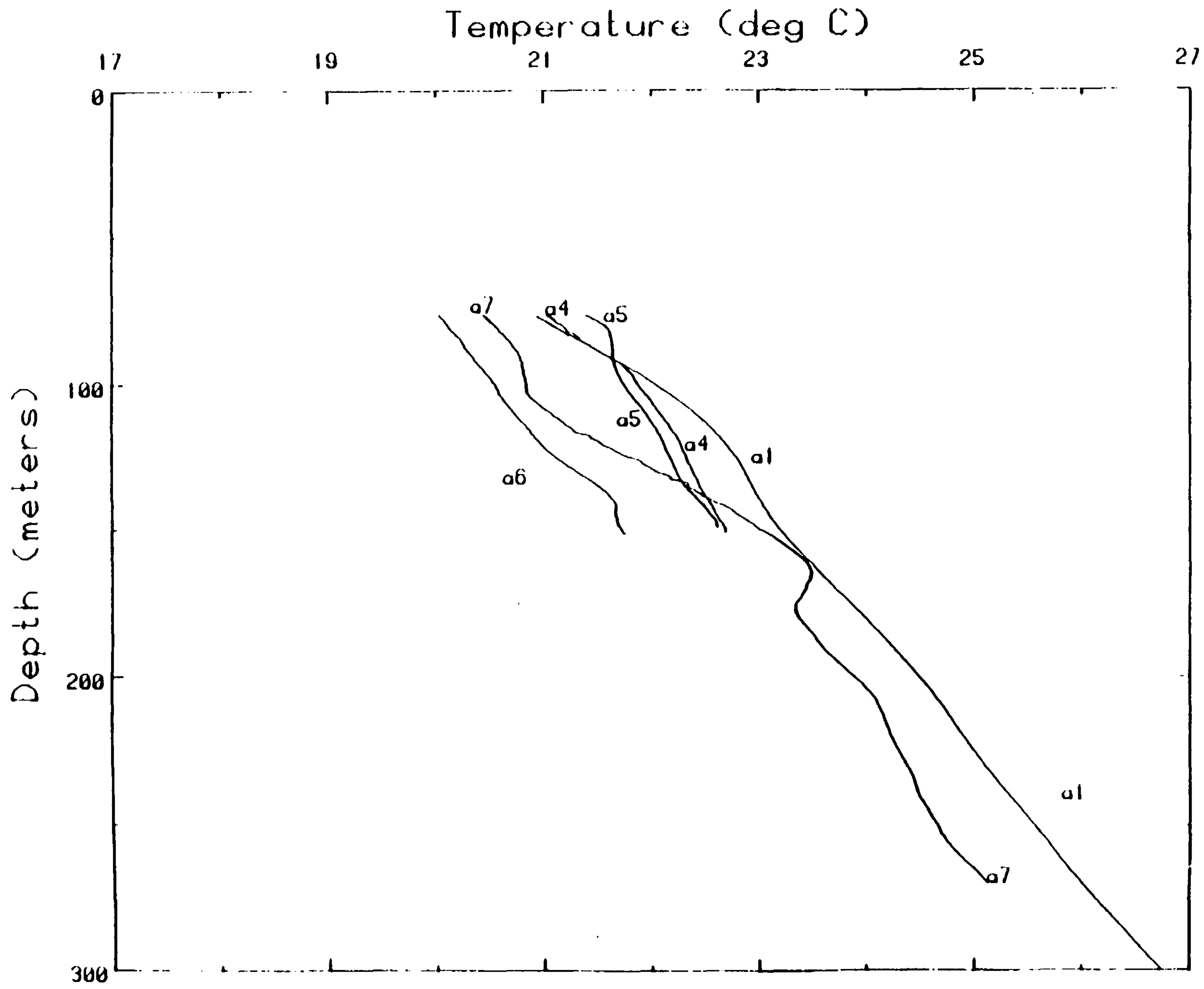

Figure 11. Temperatures from UE25a1 & the "conductor holes", Yucca Mtn.

Temperature gradients within individual formations were combined with thermal conductivity determinations by Lappin and others (1982) (above ~900 m) and our own measurements (below ~900 m) to obtain component conductive heat flows for each formation (table 2). The six interval heat flows increase systematically with depth, lending support to our preliminary interpretation. If we assume that one-dimensional steady-state vertical water flow is responsible for the observed increase in heat flow with depth and that the material is saturated, we may perform a simple calculation to estimate the seepage velocity and penetration depth of the vertical water flow.

For the idealized conditions assumed, conservation of mass and energy requires that the temperature θ be related to the vertical volumetric flow rate of interstitial water V by the differential equation (see e.g., Lachenbruch and Sass, 1977)

$$\frac{d}{dz} k\frac{d\theta}{dz} = -\rho' c' V\frac{d\theta}{dz} \qquad (1)$$

where z is depth and V is taken positive for upward flow. Density and specific heat at constant pressure for the water are represented by ρ' and c', respectively; k is thermal conductivity of the saturated aggregate. Their values are approximately

$$\rho' c' = 1 \text{ cal/cm}^3\ {}^\circ\text{C} = 4.2 \times 10^6 \text{ J/m}^3\text{K} \qquad (2a)$$

$$k = 4.3 \text{ mcal/cm sec }{}^\circ\text{C} = 1.8 \text{ W/m K} \qquad (2b)$$

The vertical conductive heat flow q (positive upward) is defined by

$$q = k\frac{d\theta}{dz} \qquad (3)$$

Combining (1) and (3) yields a relation between vertical heat flow and volumetric flow velocity V (e.g., cm^3 of water per cm^2 of cross sectional area

TABLE 2. Heat-flow determinations, USWG1

Depth interval	Formation	Γ*	SE	N[†]	‹K›[††]	SD	SE	Heat flow	
m		°C km^{-1}			Wm^{-1} K^{-1}			mWm^{-2}	HFU
91–427	Paintbrush tuffs	16.32	0.08	0**	1.58	30	10	26±2	0.62
427–549	Calico Hills tuffs	21.51	0.27	16**	1.31	0.11	0.03	28±1	0.67
610–1006	Crater Flat tuffs	23.01	0.08	27	1.65	0.28	0.05	38±1	0.91
1067–1204	Flow Breccia	31.16	0.19	4	1.65	0.26	0.13	51±4	1.23
1219–1524	Lithic rich tuffs	29.04	0.03	10	1.81	0.13	0.04	53±1	1.26
1524–1697	Older tuffs	28.09	0.09	11	1.93	0.13	0.04	54±1	1.30

*Γ – least-squares temperature gradient ± Standard Error (SE).

†N = number of samples measured.

**These are estimates from Tables 9 and 10 of Lappin and others (1982).

††Harmonic mean thermal conductivity ± Standard deviation (SD) and Standard Error (SE) over the least-squares interval

of aggregate per unit time)

$$\frac{dq}{dz} = -Aq \tag{4}$$

where

$$A = \frac{\rho' c' V}{k} \tag{5}$$

According to (4), the conducted heat flow at the surface q_o, is related to the conducted heat flow $q(z)$ at depth z by

$$q(z) = q_o\, e^{-\bar{A}z} \tag{6}$$

where

$$\bar{A} = \frac{1}{z} \int_0^z A\,dz \tag{7}$$

Thus $\bar{A}$ is a representative value of A in the depth range [0,z].

To obtain an order of magnitude estimate of $\bar{A}$ (and hence V, equation 5), we neglect its variation with depth and fit a curve of form (6) to heat flows q(z) determined over a number of depth intervals in the hole. The interval heat flows were plotted as a function of the depth of the mid-point of the interval (fig. 12) and a least-squares regression curve (also shown in the figure) was calculated. The parameters of equation 6 obtained from the regression analysis are:

$$q_o = 0.53 \text{ HFU} = 22.4 \text{ mW/m} \tag{8}$$

$$\bar{A} = -6.12 \times 10^{-4} \text{ m}^{-1} \tag{9}$$

The correlation coefficient is 0.95, and the maximum departures from the least-squares line are about ±5 mW/m^2 which we consider reasonable in view of the idealized nature of the model and likely sources of measurement error.

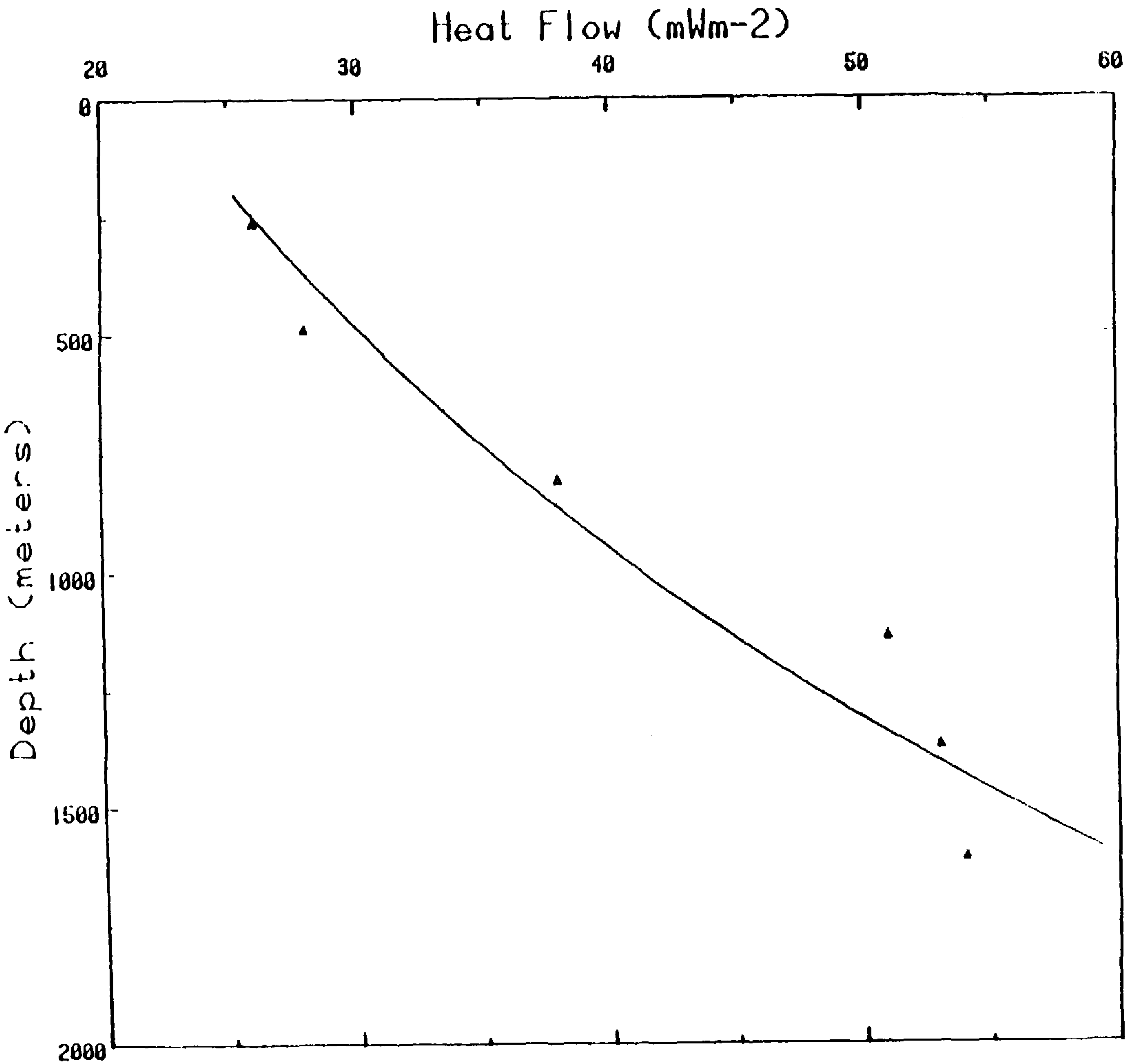

Figure 12. Interval heat flows (from Table 2) as a function of the depth of the interval.

Combining equations 2, 5, and 9 yields an estimate of the vertical seepage velocity

$$V = \frac{-k}{\rho' c'} \bar{A} \tag{10a}$$

$$= 2.6 \times 10^{-10} \text{ m/s} = 8 \text{ mm/y} \tag{10b}$$

The average particle velocity of the pore water is obtained from V by dividing by the porosity; i.e., it would be 40 mm/yr (40 m/1000 yrs) for a porosity of 20% (10b).

If we assume that this simple flow pattern persists to some depth z^*, beneath which the heat flow is equal to the regional value $q(z^*)$, we can estimate the depth of vertical flow from equations 6, 8, and 9

$$z^* = \frac{-1}{\bar{A}} \ln \frac{q(z^*)}{q_o} \tag{11a}$$

$$\cong 2 \text{ km} \qquad \text{if } q(z^*) \cong 80 \text{ mW/m} \sim 2 \text{ HFU} \tag{11b}$$

$$\cong 2.5 \text{ km} \qquad \text{if } q(z^*) \cong 100 \text{ mW/m} \sim 2.5 \text{ HFU} \tag{11c}$$

Although this model represents a gross idealization, it leads to numerical values for vertical seepage velocity (10b) and circulation depth (11b and c) that are reasonable in order of magnitude and consistent with other information.

SUMMARY

From thermal measurements in about 60 wells, it appears that over much of the Nevada Test Site, including the Yucca Mountain site, the steady-state, conductive thermal regime has been altered significantly to depths as great as 2 to 3 km by water movement having a vertical component of seepage velocity of several meters per millenium. Regionally, the predominant vertical flow in this depth range is downward, but local upwellings exist. The measurements suggest 2- or 3-dimensional flow which in turn suggests that lateral movement of ground water must also be involved; however, the thermal measurements provide no measure of lateral velocities. In summarizing these results, we emphasize that of all the holes we have studied at NTS, only Ue17e was completed in the manner required for a confident analysis of the thermal effects of natural ground-water flow. In the other holes, the annulus was not blocked with grout, and uncertainties persist regarding possible complications of local vertical flow within the annulus behind the well casing.

In the Yucca Mountain area itself, measurements in wells deeper than 1 km suggest a downward water movement with seepage velocity on the order of 1-10 mm/y.

References

Lachenbruch, A. H., 1981, Temperature effects of varying phase composition during the steady vertical flow of moisture in unsaturated stratified sediments: U.S. Geological Survey Open-File Report 81-1220, 11 p.

Lachenbruch, A. H., and Sass, J. H., 1977, Heat flow in the United States and the thermal regime of the crust, in Heacock, J. H., ed., The Earth's Crust: American Geophysical Union Geophysical Monograph 20, American Geophysical Union, Washington, D. C., p. 626-675.

Lappin, A. R., Van Buskirk, R. G., Enniss, D. O., Butters, S. W., Prater, F. M., Muller, C. S., and Bergosh, J. L., 1982, Thermal conductivity, bulk properties, and thermal stratigraphy of silicic tuffs from the upper portion of hole USW-G1, Yucca Mountain, Nye County, Nevada: Sandia National Laboratories Report SAND 81-1873.

Sass, J. H., Blackwell, D. D. Chapman, D. S., Costain, J. K., Decker, E. R., Lawver, L. A., and Swanberg, C. A., 1981, Heat flow from the crust of the United States, in Touloukian, Y. S., Judd, W. R., and Roy, R. F., eds., Physical Properties of Rocks and Minerals: McGraw-Hill Book Company, p. 503-548.

Sass, J. H., Lachenbruch, A. H., and Mase, C. W., 1980, Analysis of thermal data from drill holes UE25a-3 and UE25a-1, Calico Hills and Yucca Mountain, Nevada Test Site: U.S. Geological Survey Open-File Report 80-826, 25 p.

Sass, J. H., Lachenbruch, A. H., Munroe, R. J., Greene, G. W., and Moses, T. H., Jr., 1971, Heat flow in the western United States: Journal of Geophysical Research, v. 76, p. 6376-6413.

Swanberg, C. A., and Morgan, P., 1978, The linear relation between temperature based on the silica content of groundwater and regional heat flow: A new heat flow map of the United States: Pure and Applied Geophysics, v. 117, p. 227-241.

Winograd, I. J., and Thordarson, W., 1975, Hydrogeologic and hydrochemical framework, South-Central Great Basin, Nevada-California, with special reference to the Nevada Test Site: U.S. Geological Survey Professional Paper 712-C, 126 p.

APPENDIX A-1.

Thermal conductivity, density, and apparent porosity of tuffs

from USWG1 (measured at ~25°C)

TABLE A-1 Thermal conductivity, density, and apparent porosity of tuffs from USWG1 (measured at ~25°C)

Depth, m	Formation	Lithology	K $Wm^{-1} K^{-1}$	$\rho^{\dagger}$ $gm\ cm^{-3}$	$\phi^{\dagger\dagger}$ %
868.1	TcfT	Moderately welded tuff	1.80	2.20	22.2
892.8	TcfT	Moderately welded tuff	1.94	2.34	15.3
892.9	TcfT	Moderately welded tuff	1.87	2.36	15.7
899.8	TcfT	Moderately welded tuff	1.87	2.37	13.7
930.2	TcfT	Moderately welded tuff	1.42	2.11	22.4
940.4	TcfT	Moderately welded tuff	1.54	2.13	20.4
967.3	TcfT	Zeolitized partially welded tuff	1.62	2.29	16.6
983.6	TcfT	Zeolitized non-welded tuff	1.67	NM	NM
1013.8	TcfT	Vitrophyre	1.67	2.29	18.2
1044.5	TcfT	Vitrophyre	2.00	NM	NM
1065.6	TcfT	Vitrophyre	1.80	2.34	15.6
1091.6	Tfb	Flow Breccia	1.86	2.44	12.1
1123.4	Tfb	Flow Breccia	1.43	2.34	14.5
1157.9	Tfb	Flow Breccia	1.95	2.55	3.2
1187.9	Tfb	Flow Breccia	1.49	2.34	12.5
1219.4	Trt	Zeolitized partially welded tuff	1.65	2.19	15.7
1253.6	Trt	Zeolitized partially welded tuff	1.80	2.25	13.6
1280.1	Trt	Zeolitized partially welded tuff	1.88	2.16	16.5
1319.9	Trt	Zeolitized partially welded tuff	1.72	2.24	16.7
1349.2	TrT	Zeolitized partially welded tuff	1.77	2.23	15.4
1389.4	TrT	Zeolitized partially welded tuff	1.86	2.32	14.5
1419.3	TrT	Zeolitized partially welded tuff	1.75	2.27	16.8
1450.7	TrT	Zeolitized partially welded tuff	1.96	2.37	11.0

TABLE A 1 Thermal conductivity, density, and apparent porosity of tuffs from USWG1 (measured at ~25°C)--continued

Depth, m	Formation	Lithology	K $Wm^{-1}K^{-1}$	ρ[†] $gm\ cm^{-3}$	ϕ[††] %
1511.6	TrT	Zeolitized non-welded tuff	1.68	NM	NM
1540.0	TtA	Silicic tuff densely welded	1.98	2.30	12.4
1573.0	TtA	Silicic tuff densely welded	1.98	2.28	14.0
1600.0	TtA	Zeolitized tuff densely welded	2.15	2.30	14.8
1632.6	TtB	Zeolitized tuff bedded	2.12	2.35	11.3
1675.7	TtC	Zeolitized non-welded tuff	1.70	NM	NM
1716.9	TtC	Zeolitized tuff densely welded	1.94	2.39	11.2
1747.7	TtC	Devitrified moderately welded tuff	1.91	2.46	9.2
1754.5	TtC	Devitrified moderately welded tuff	1.85	2.43	11.0
1783.3	TtC	Devitrified moderately welded tuff	1.97	2.47	8.6
1813.8	TtC	Silicified moderately welded tuff	1.89	2.49	5.8
1814.0	TtC	Silicified moderately welded tuff	1.86	2.31	13.6

*Tcft, tram unit, Crater Flat tuff
Tfb, Flow Breccia
TrT, Lithic-rich tuff
Tt, older ash-flow and bedded tuff, units A, B, and C

†Saturated density NM, not measured (because of disintegration of specimen).

††Apparent porosity = $\frac{\text{saturated weight} - \text{dry weight}}{\text{saturated weight}}$ NM, not measured.

Scott and Whitney, 1987

3374

...COMPARISON OF LARAMIDE UPLIFTS IN SOUTHERN ... AND NORTHERN WYOMING

Nº 127939

[illegible], Dept. of Geology, Western Michigan Univ., [illegible]

...Laramide uplifts of southern Montana differ from those in ... Wyoming in several important ways: They are more closely spaced (35-130 km compared with 100-200 km); they are temporally and spatially associated with Late Cretaceous magmatic activity; and they involve ... well foliated and layered basement rocks. The difference in spacing of the principal uplifts may be closely related to the presence of associated magmatism in Montana and absence of such activity in Wyoming. Thermal gradients should have been significantly higher in the Montana foreland in Late Cretaceous time owing to somewhat shallower depths to the brittle-ductile transition. Analysis of folding of a brittle layer above a ductile substrate (Fletcher, 1984) has shown that the ratio of spacing (S) to the thickness of the brittle layer (H) is 4-5/H/6. Application of this analysis to the Laramide uplifts in Montana indicates that H may have been as shallow as 6-8 km at the western edge of the foreland and that it deepened (20-30 km) eastward in the Beartooth Mountains. By contrast, in Wyoming H may have been 16-25 km on the west (Moxa Arch - Wind River uplift) and have deepened eastward to Moho depths. The contrast in predicted brittle layer thickness dictates higher thermal gradients in the Montana foreland. Uplift spacing shorter than about 40 km corresponds to unrealistically high thermal gradients. The closest spaced primary uplifts in Montana are about 35 km apart and may therefore be partly controlled by pre-existing fault zones. More closely spaced secondary folds are clearly controlled by pre-existing fault zones and not the thickness of the brittle layer. The more highly foliated basement rocks in Montana locally influence the geometry of foreland folds, but they do not appear to significantly ... uplift spacing or thrust sheet thickness.

Nº 122800

Pleistocene Response of the Madison River to Regional Base Level Change for the Madison Valley, Southwest Montana

SCHNEIDER, Nicholas P. and RITTER, Dale F., Department of Geology, Southern Illinois University, Carbondale, IL 62901

...by the Madison River during the late Tertiary and Pleistocene culminated in an extensive alluvial surface, the Cameron Bench, that served as local base level for alluvial fans ... by major tributary streams. Alluvium in the oldest segment of Cedar Creek fan may ... that can be traced directly into a moraine of Bull Lake age. The oldest segment of this fan appears to grade to a level below the Cameron Bench, indicating that incision by the Madison River near Ennis began prior to Bull Lake equivalent glaciation. ... of Ruby Creek, 45 km upstream from Cedar Creek, a Bull Lake outwash fan is graded to the Cameron Bench. In addition, Pinedale age terraces of Ruby Creek and equivalent outwash fans in the Madison Valley from Ruby Creek are graded to a level lower than the Cameron Bench. Madison River incision in this valley reach started after the Bull Lake glaciation. ... suggest that entrenchment of the Madison Valley floor began at its northern ... while aggradation of the Cameron Bench gravel was still occurring upstream. Assuming a Bull Lake age of between 100 ka and 140 ka B.P., the minimum rate of vertical cutting by the Madison River at the Ruby Creek reach has been about 40 - 60 cm/10^3 years. ... use this estimated rate and the level to which the oldest segment of Cedar Creek ... we calculate that the locus of incision by the Madison River migrated headwardly ... the Late Pleistocene at a rate of 260 - 330 m/10^3 years. The actual rates of incision were probably greater because entrenchment was interrupted by episodic valley filling with glacial outwash. South of the Ruby Creek-Cedar Creek reach, incision and aggradation are controlled by the imprint of more local tectonic controls which affect the ... of the basin.

PRECAMBRIAN GEOLOGY OF THE GRANBY AND STRAWBERRY LAKE QUADRANGLES, COLORADO

Nº 122580

SCHNEIDER, David A., Geology Dept., Augustana College, Rock Island, IL 61201

Granby and Strawberry Lake quadrangles straddle the east margin of the Front Range west of Boulder, Colorado. Exposed Precambrian rocks are Proterozoic in age and consist of 1.7 b.y. old high grade metamorphic rocks and 1.7 b.y. old and 1.4 b.y. old plutonic igneous rocks.

The metamorphic rocks are mainly migmatitic biotite schist (biotite-plagioclase-microcline-sillimanite-garnet-cordierite) which was formed in the upper amphibolite facies (630-720 degrees C, 4-6 kb). ... grade metamorphism, increasing to the east, produced several ... zones with the lowest grade assemblage being biotite-quartz-... . Foliated granitic gneiss and granodiorite ..., and minor amphibolite, quartzite, marble, ... calc-silicate gneisses are also present.

Intrusions into the metamorphic rocks about 1.7 b.y. ago produced a ... and a few smaller plutons of Boulder Creek Granodiorite. Intense deformation, roughly contemporaneous with the plutonism and prograde metamorphism, created at least three systems of superposed folds ... fold systems are tentatively correlated with fold systems ... identified in other parts of the Front Range. Intrusions about 1.4 b.y. ago produced a stock and numerous smaller ... of Silver Plume Granite. These intrusions are associated with ..., if any, metamorphism and only minor folding. Minor quartz ... porphyry dikes are probably contemporaneous with the Silver Plume Granite, and minor dikes and irregular bodies of lamprophyre may be contemporaneous with either or both major periods of intrusion.

Faults with mylonite in the area may have undergone one or more periods of movement from about 1.7 b.y. ago up to at least about 1.2 b.y. ago.

LANDSLIDE DAMMING OF MOUNTAIN STREAMS

Nº 132620

SCHUSTER, Robert L., U.S. Geological Survey, Box 25046, M.S. 966, Denver, CO 80225, COSTA, John E., U.S. Geological Survey, 5400 MacArthur Boulevard, Vancouver, WA 98661

Landslide damming of rivers and streams is a significant natural hazard in mountainous areas. At least one historic landslide dam is higher than the world's highest constructed dam: the 1911 Usoy landslide dam, U.S.S.R., at least 550 m high, versus the recently constructed Nurek Dam, U.S.S.R., 300 m high. Although they are formed by various kinds of mass movements in different physiographic settings, the largest and most hazardous landslide dams are most commonly caused by rock slides and rock or debris avalanches in steep walled narrow canyons in mountainous terrains.

Individual landslide dammed lakes may last for several minutes or for several thousand years, depending on a number of factors, including rate of inflow of water and sediment to the impoundment; size and geometry of the landslide dam; volume and physical properties of the dam materials; rate of seepage through the dam; and the use of engineering control measures, such as artificial spillways, diversions, and tunnels, and planned breaching by blasting or conventional excavation. As is the case for engineered dams, landslide dams result in backwater flooding of their upstream impoundment areas. However, unlike the vast majority of engineered dams, sooner or later most landslide dams are overtopped by their reservoirs. Many of them have failed catastrophically, causing major downstream flooding. Casualties from individual floods have reached into the thousands. Secondary effects of landslide dam failures include additional landsliding as reservoir levels rise or rapidly fall, aggradation downstream from the failed dams, and rapid channel changes both downstream and immediately upstream.

SEDIMENTOLOGICAL EFFECTS OF THE TECTONIC TRANSITION FROM FOLD-THRUST DEFORMATION TO THRUST-CORED UPLIFT, PROXIMAL SEVIER FORELAND (SIX MILE-PRICE RIVER-NORTH HORN INTERVAL), CAMPANIAN-PALEOCENE OF UTAH

Nº 120025

SCHWANS, Peter, Dept. of Geology & Mineralogy, The Ohio State University, Columbus, OH 43210

Sedimentation at the thrust belt-foreland basin boundary in central Utah during the Turonian to Santonian was controlled by eustasy. Depositional geometries reflect shoreline oscillation under a varying flux of siliciclastics. Rapid and voluminous influx of conglomerates during the early Campanian, however, marks renewed thrust sheet erosion with final thrust movement of the Canyon Range thrust. As a result of thrusting, pebbly shoreface, sandy distributary braidplain, and alluvial fan sedimentation spread eastward and overstepped the marine environments. Campanian sedimentation is marked by west-east flowing braid-fan drainages at the thrust front debouching into a narrow coastal braidplain. During the late Campanian to Maastrichtian the integrated depo center and foredeep was segmented by thrust-cored uplifts. Campanian synorogenic clastics in central Utah are truncated by an erosional unconformity above which upper Campanian to Maastrichtian clastics offlap. Late Campanian sedimentation patterns show rapid infilling of paleotopography and burial of Campanian folds. Drainages were confined to the structural basins, and detritus was derived from adjacent highs, with conglomerate lithologies reflecting erosion of uplifted Cretaceous rocks. At the thrust front, upper plate Precambrian quartzites were thrust against and over drag-folded conglomerates of Campanian age. Late Campanian conglomerates overlap upper plate rocks, disconformably overlie Campanian deposits adjacent to the thrust front, and farther east, truncate underlying Cretaceous rocks to a varying degree. Paleocene clastics overlie and thin westward against the late Campanian conglomerates.

THE UPPER CRUSTAL DETACHMENT SYSTEM AT YUCCA MOUNTAIN, SW NEVADA

Nº 133313

SCOTT, Robert B., and WHITNEY, John W., U.S. Geological Survey, Federal Center, MS 913, Denver, CO 80225

The pattern of normal and strike-slip faults in Miocene volcanic strata and Quaternary surficial deposits suggests that a shovel-shaped, upper crustal detachment system underlies a 10x25 km segment of Yucca Mountain. The detachment system consists of three parts: a basal detachment fault, strike-slip faults, and a newly recognized breakaway zone. Steep east dipping normal faults in the upper plate of the detachment system do not appear to offset the northwest striking, right lateral strike-slip faults in the vicinity of Yucca Wash on the northern side of the mountain and the northeast striking, left lateral Stagecoach Road fault in the southern part of the mountain. Ridges of 13 Ma tuffs are offset in a left lateral sense as much as 1 km and drainage channels on Quaternary bedrock pediments and on Quaternary deposits are offset 10-30 m across the Stagecoach Road fault. Both strike-slip zones appear to merge into the major west dipping Bare Mountain-Paintbrush Canyon normal fault zone near the eastern edge of the mountain, to form an arcuate breakaway zone. This zone is accentuated by a series of valleys 0.5 to 2 km wide; the southern extension of this zone intersects the Lathrop Wells cone, a Quaternary basaltic volcano. As much as 4 km of apparent vertical offset occurs in buried units (>9-14 Ma) exposed in stand ranges along the Bare Mountain fault. The amount of offset on the normal faults and strike-slip faults appears to decrease northward, suggesting a clockwise rotation of the detachment block from a pivot point in the northern part of Yucca Mountain. The basal part of the detachment system probably follows the strong physical property boundary between nonwelded Tertiary tuffs and Paleozoic carbonates. Gravity models predict this boundary to increase from a depth of 1 km in the eastern part of the mountain (confirmed by drilling) to as much as 4 km in the northwestern part. Kinematic constraints require westward movement of the upper plate of the detachment system toward Crater Flat. We conclude that a detachment model provides the best explanation for the structural features and tectonic evolution of Yucca Mountain.

A THIRD CALDERA IN THE GILA WILDERNESS, SW NEW MEXICO

Nº 126423

SPAHAR, Sheila J. and ELSTON, Wolfgang E., Dept. of Geology, University of New Mexico, Albuquerque, NM 87131

Up to 150 m of a silicic ash-flow tuff in the Mogollon-Datil volcanic field of southwestern New Mexico appear to be associated with a small previously undescribed caldera. Its probable center is located slightly southeast of the intersection of the Bursum and Gila Cliff Dwellings calderas in the Gila Wilderness. The ash-flow tuff associated with the proposed caldera is younger than the Shelley Peak Tuff (28.52 Ma; McIntosh, 1986), and older than the Bloodgood Canyon Tuff (28.36 Ma; McIntosh, 1986). Ratté and Gaskill (1975) mapped it as Trw, the welded tuff facies of the rhyolite of the Diablo Range which occurs above and below it. The eruption of the ash-flow tuff was a brief explosive interlude in the extrusion of these voluminous lava domes.

Evidence for a distinct caldera includes: 1) presence of megabreccia at the base of the ash-flow tuff, 2) confinement to a basin of about 80 km², 3) association with overlying and underlying rhyolitic lavas, and 4) thinning of the unit from the basin center to its edges. If ring fracture faults were associated with this caldera, they have been nearly obliterated by later extrusion of the rhyolite of the Diablo Range.

Trw is compositionally zoned in terms of major elements and several trace elements including Rb, Sr, Y, Zr, Nb, and Ba. It is mineralogically similar to the high-silica Bloodgood Canyon Tuff (major minerals are quartz and sanidine, with sparse biotite), but is intermediate between the older Shelley Peak Tuff and the Bloodgood Canyon Tuff in terms of SiO_2, CaO, and Fe_2O_3 weight percents. Trace element abundances as well as major element chemistry in the Shelley Peak Tuff, Trw, and the Bloodgood Canyon Tuff are consistent with three temporally distinct eruptions from an evolving magma system. The succession of these three units mirrors the overall development of the Mogollon-Datil volcanic field from calcic earlier eruptions to later high-silica eruptions.

PALEOGEOGRAPHIC AND STRUCTURAL EVOLUTION OF THE POWDER RIVER BASIN, LATE CRETACEOUS TO OLIGOCENE: DID A LAKE FORM AS A RESULT OF A PALEOCENE PALEOSLOPE REVERSAL?

Nº 126676

SEELAND, David, U.S. Geological Survey, Box 25046, MS 939, DFC, Denver, CO 80225

Fluvial crossbedding of strata ranging from Late Cretaceous to Oligocene age is being studied to determine the paleogeographic and structural evolution of the Powder River Basin of northeast Wyoming and southeast Montana.

During most of the Late Cretaceous, fluvial drainage generally was eastward toward the Western Interior Seaway. Fluvial crossbed vector-means from the latest Cretaceous (Maastrichtian) Lance Formation indicate regional tilting to the south or southwest, perhaps signaling the initiation of Laramide tectonism.

Southeasterly crossbed vector-means at five localities in the basal Paleocene Fort Union Formation (Tullock Member) in the southeastern part of the basin show an unchanged regional paleoslope. A northerly paleoslope in the Tullock Member on the east side of the basin near the Montana-Wyoming State line is suggested by vector-mean crossbed directions at three localities.

Crossbed vector-means at 17 localities around the periphery of the basin in the middle and upper Fort Union Formation (Lebo and Tongue River Members) provide preliminary evidence for centripetal drainage into a lake.

Published paleocurrent directions from the uppermost Fort Union Formation indicate that the basin tilted northward or was filled by latest Paleocene time. Crossbed measurements in the early Eocene Wasatch Formation at 34 localities show a north-flowing basin-axis fluvial system. Oligocene drainage in the northern and central parts of the basin was to the northeast while a major east-flowing river crossed the southern margin of the basin.

STYLOLITES IN HYDROTHERMALLY-ALTERED IGNEOUS ROCKS

Nº 133093

SHANNON, James R., and NELSON, Eric P., Department of Geology, Colorado School of Mines, Golden, Colorado 80401

Stylolites are thin surfaces characterized by mutual column and socket interdigitations, and generally are believed to form by pressure dissolution during diagenesis or deformation. They usually form in carbonate rocks, less commonly in sandstones, and are rarely reported in igneous rocks. We have discovered four occurrences (Republic, WA; Henderson Mine, CO; and two in the Sawatch Range, CO) of stylolites in aphanitic, porphyritic igneous rocks. In the Sawatch Range, stylolites are present near and subparallel to the base of lava flows and the margins of dikes. They are present as single, en echelon, or braided surfaces and are sometimes connected by thin extension gashes which form at a high angle to the stylolite plane. Stylolites truncate phenocrysts. Stylolites and extension gashes contain thin (0.005 to 0.70 mm), volatile fillings of phlogopite, biotite, chlorite or sericite, which correspond to the dominant hydrothermal alteration mineralogy of the host.

Stylolites form in various igneous rocks (e.g. rhyolite; latite) affected by different types of hydrothermal alteration (e.g. propylitic; phyllic) and are spatially associated with various ore deposit types (e.g. porphyry Mo at Henderson Mine; hydrothermal Au at Republic, WA). Compared to sedimentary rock stylolites, those in igneous rocks are generally more subtle and contain a hydrothermal mineral assemblage. Stylolite fillings may represent residual accumulations of less soluble constituents of the host, or precipitates formed during flow of hydrothermal fluids along the stylolite. They may form during a tectonic event or a younger event genetically unrelated to the host. The amount of rock removed by dissolution is at least millimeters for each stylolite. The important conditions for controlling stylolite formation in igneous rocks appear to be: (1) very fine-grain size, (2) elevated temperatures, (3) available hydrothermal fluids, and (4) differential stress. We predict stylolites will form in igneous rocks where these conditions are met.

STRUCTURAL AND TECTONIC CONTROLS ON EMPLACEMENT OF DIAMONDIFEROUS KIMBERLITE IN THE COLORADO-WYOMING PROVINCE: EVIDENCE FROM THE SLOAN GROUP

Nº 126571

SHAVER, Kenneth C., Long Lac Mineral Exploration, 2020 Airway Avenue, Fort Collins, Colorado 80524

Data acquired during recent economic evaluation of the Sloan 1,2,3,5 and 6 kimberlites has provided new insights into the various factors which affect the morphology and location of diamondiferous kimberlites in Colorado.

Although previously thought to be separate bodies, SL-1, SL-2 and SL-3 are now recognized as parts of the same complex. SL-1 is an elongate diatreme which follows the major foliation of the gneisses which it intrudes. SL-2 is a vertical dike which parallels the orientation of a much older tholeiite dike swarm. The kimberlite of SL-2 varies from hypabyssal facies near its distal end to diatreme facies where it meets SL-1. The SL-3 exposures are outcrops of sub-horizontal sheets which appear to be offshoots of SL-1 and SL-2.

Two miles to the north, approximately 100 feet of Precambrian gneiss separates the SL-5 and SL-6 diatremes; they probably were connected at a higher level prior to erosion. The elongated and irregulary-shaped SL-5 body exploited both fault planes and lithologic variations in the host rocks. SL-6 intruded relatively homogeneous granite, and has a classic ovoid outcrop pattern.

Regionally, the contacts of Precambrian granitic batholiths seem to have been at least as important as major fault structures in localizing the kimberlite intrusions.

Finally, the presence of diamonds in the Sloan rocks may indicate that Archean rocks of the Wyoming province underlie this portion of the Proterozoic mobile belt in Colorado.

BALANCED PALEOGEOGRAPHY AND PLIO-PLEISTOCENE UPLIFT HISTORY OF THE ROCKY MOUNTAINS

Nº 135436

SHAW, C.A., Museum, Cooperative Institute for Research in Environmental Sciences, and Department of Geology, University of Colorado, Boulder, CO 80309-0216.

Examination of mass balance relationships between a basin and its source area within an assumed closed system yield estimates for paleotopography and paleobathymetry. These balanced paleogeographic maps model 1) the replacement of sediments from their site of deposition back to their site of erosion, 2) isostatic adjustments associated with the loading and unloading of sediment, pore fluids, and sea water, and 3) sea level fluctuations. The amount of uplift is then estimated by comparing the predicted yield during erosion of the preliminary paleotopographic maps to the sediment yield observed in the geologic record.

Rates and magnitudes of the uplift occurring in the western-central United States resulting from the development of the Rocky Mountains were estimated through balanced paleogeographic modeling. The major uplift event is shown, by this method, to have begun no earlier than 3-4 Ma, which is consistent with geohistory and stratigraphic/structural analyses along the Front Range. Support for the late uplift phase of the Rocky Mountains is present in sediment mass-age distribution data. If the region had been steadily uplifted over the past 10 my, and had been eroded by rivers having sediment yields similar to the modern Mississippi from 10 Ma when the average elevation was 231 m to the present when the average elevation is 710 m, the sediment yield would be nearly twice the actual observed mass. To conform to sedimentary mass balance principles, the uplift, and resultant large sediment yields, must have occurred since the Middle Pliocene.

1777

Scott + Rosenbaum 1986

important for the interpretation of vibrational spectra, the prediction of dynamics when spectral data are lacking, determining phase transition mechanisms (e.g., soft-mode behavior), and the development of thermodynamical models. There have been numerous mineralogical applications of the lattice-dynamical methods developed originally for simple ionic crystals. These methods involve the use of the harmonic or quasiharmonic approximation with rigid, spherical ions that interact via long-range Coulomb and short-range (mainly repulsive) terms. This type of model has been improved by various schemes that relax the spherical rigid-ion approximation and/or introduce anharmonic effects. These extensions generally introduce an excessive number of free parameters. Considerable advances in the field have been made by recent first-principles calculations of the appropriate interactions. These calculations provide important constraints on the parameters, but more significantly, they provide a test of key assumptions in these models, such as those concerning the character of the charge distribution in the crystal. The current level of theory is most accurate for closed-shell ions, and important applications are found for phases in the system BaO-MgO-Al_2O_3-SiO_2. The role of anharmonicity can be ascertained by comparing various perturbative corrections to the harmonic approximation or (more directly) by comparing the results of molecular dynamics and Monte Carlo simulations. The prospect for theoretical treatment of the dynamical properties of real (i.e., disordered) minerals is enhanced by advances in computational methods. Both accurate calculations of the potentials and simulation of large, complex structures are thereby possible.

Fault Kinematics and Dynamics
Room 305 Mon AM
Presider, J. Rundle
Sandia National Laboratory
R. Bilham
LDGO

T11C-01 0830h

Kinematic Analysis of Fault-slip Data

RANDALL MARRETT (Department of Geological Sciences, Cornell University, Ithaca, New York 14853)

Fault-slip data are powerful kinematic indicators because faults in deformed regions are often pervasive at the tectonic scale, independent geologic criteria can often be used to distinguish among faults of distinct events, and rotational effects associated with non-coaxial deformation can be addressed with fault-slip data. Analysis of fault-slip data (consisting of unit fault plane normal and slip direction vectors n and s respectively) by inversion or grid search techniques using the following equation yields an instantaneous deformation tensor (∇v) describing the regional kinematics of the fault-slip process:

$$s = \frac{v}{|v|} = \frac{\nabla v \cdot n - (n \cdot \nabla v \cdot n)n}{|\nabla v \cdot n - (n \cdot \nabla v \cdot n)n|}$$

where v represents the average relative instantaneous velocity between fault-bounded blocks. This equation is identical in form to the equation used in previous dynamic methods of fault-slip analysis, however it differs in that the solution tensor is not constrained to be symmetric. The asymmetry of a deformation tensor gives it more degrees of freedom than a stress tensor so that results have lower standard deviations. Analysis of the asymmetry of a deformation tensor provides a description of simple shear-type rotation, which is inherent in the fault-slip process. Previous dynamic methods ignore this information in fault-slip data and attribute it to the noise which constitutes error in the data. Another advantage of the proposed kinematic method is that it requires no assumptions concerning the constitutive law for fault-slip, unlike previous dynamic methods. Independent geologic data on the magnitude of any one deformation rate parameter constrain the magnitude of the instantaneous deformation tensor.

T11C-02 0845h

A geodetic test for the local slip vector on creeping sections of the San Andreas fault in central California

Kenneth Hurst
Roger Bilham

Lamont Doherty Geological Observatory, Palisades, NY 10964, * also Dept. of Geological Sciences, Columbia University

A 6 degree discrepancy exists between the mean strike of the San Andreas Fault in central California and the inferred plate slip vector derived from global plate motions. The inferred fault normal shortening across the San Andreas system given this convergence vector is ~6 mm/a, a value that is considered too large from a consideration of geological evidence.

We have analysed the creeping section of the fault as a contiguous sequence of straight segments. The strike and slip-rate in each segment are used to compute convergence or divergence transverse to the segment for various possible regional slip vectors. These estimates of fault-normal displacements are then compared to observations of fault strain from short baseline (~1-5 km aperture) fault crossing measurements made by the US Geological Survey in the last decade.

Noise in the data and uncertainties in the width of the fault zone prevent an accurate estimation of the local slip vector. The geodetic data confirm that transtensional and transpressional processes are active to a greater or lesser extent in all segments: the largest transtensional values occur at Parkfield. A surprising result of the study is that measured along-fault and across-fault strain rates exceed 4 μstrain/a at three locations.

T11C-03 0900h

The Patch Model for Earthquakes, and the Possibility of Conserved Quantities During Faulting*

JOHN B. RUNDLE (Sandia National Laboratories, Albuquerque, NM 87185)
HIROO KANAMORI (Seismological Laboratory, California Institute of Technology, Pasadena, CA 91125)

We address the problem of constitutive laws for slip on fault surfaces. In particular, we propose the hypothesis that faults are made up of Patches (like the patches on a patchwork quilt) each of which slips as a coherent unit during large earthquakes. Moreover, slip on each patch is governed by the property that the static stress-drop on that patch is a constant for all events which involve the patch. Thus, both the static stress-drop and the area of each patch can be regarded as conserved quantities. It can easily be shown that the moment produced by slip on a given set of patches depends not only on the value of the patch constants, but also upon the amount of temporal overlap of slip that the various patches display during the event. Thus the maximum moment release occurs when all patches slip exactly simultaneously, while the minimum occurs when slip of the patches is entirely sequential in time. We explore these ideas by use of an inhomogeneous fault model developed earlier, and employ them to analyze the 1906, 1942, 1958, and 1979 Colombia-Ecuador earthquake sequences.

*This work was supported by the U.S. Department of Energy under contract DE-AC04-76DP00789.

T11C-04 0915h

A Method to Estimate the Resistance Force at Transform Faults

YONGSHUN CHEN (Department of Geological and Geophysical Sciences, Princeton University, Princeton, NJ 08544)

We have developed a method to estimate the resistance force at transform faults. In our model, the oceanic lithosphere is considered as a brittle layer over a ductile layer, and the boundary between these rheologies is defined by an isotherm derived from a half-space cooling model. At a transform fault, we suggest that most of the friction occurs in the area where the two brittle layers contact. We see this estimate as a lower bound to the real total friction since resistance occurs between ductile layers also.

To apply Byerlee's friction law, we assume stress increases with increased overburden (i.e., with depth) at the transforms. This model is different from the previous models which only considered a constant shear stress at all depths. The estimated average friction per unit length is linearly proportional to the length of transform and inversely proportional to the spreading rate. An increase in length of transform will increase the average thickness of the brittle plate and also the deepest part of the plate attributes much more friction, therefore would cause an increase in the total friction. On the other hand, an increase in spreading rate would decrease the average thickness and cause a decrease in the total friction. For a typical large transform with L=100 km, and a slow spreading rate of V=10 mm/yr, the average friction per meter length of the transform is 1.6×10^{12} N/m. This is comparable to the ridge-pushing force (2.8×10^{12} N/m for 80 m.y. old oceanic plate). Our model predicts that the average energy dissipated per unit length on the transform is linearly proportional to the transform length.

T11C-05 0930h

FAULT MECHANICS AND THE KINEMATICS OF BLOCK ROTATIONS.

AMOS NUR (Geophysics Dept. Stanford University, Stanford, California 94305)
HAGAI RON AND OONA SCOTTI (Both at: Geophysics Dept., Stanford University, Stanford, California 94305)
(Sponsor: Amos Nur)

In many strike-slip tectonic settings, large rotations (up to 100 deg) of crustal blocks have been inferred from paleomagnetic data. These blocks are bounded by sets of parallel faults, which accommodate the relative motion between the blocks as regional deformation progresses. Simple geometrical considerations require that the faults must also rotate. In this paper we show that on the basis of mechanical considerations, the amount of fault rotation permissible under a stationary stress field is limited to 20 to 45 deg. Consequently, block rotations which are larger than 40 or 45 deg require more than one set of accompanying faults to accommodate the block rotation. Examples of such multiple sets with 40 to 45 deg between them, as predicted by the model, were recognized in Sistan, Iran, in Yerington, and the Lake Mead areas, Nevada, and in Southern California.

T11C-06 0945h

THE ROLE OF STRIKE-SLIP FAULTING IN THE DEFORMATION OF BASIN AND RANGE PROVINCES.

HAGAI RON (Geophysics Dept. Stanford University, Stanford, California 94305)
ATTILLA AYDIN (Dept. of Geosciences, Purdue University West Lafayette, Indiana 47907)
AMOS NUR (Geophysics Dept. Stanford University, Stanford, California 94305)
(Sponsor: Hagai Ron)

Strike-slip faults in the Basin and Range Province are often considered as passive boundaries between differentially or unevenly extended domains of highly tilted normal faults, and are therefore secondary and do not accommodate regional horizontal shear deformation.

Paleomagnetic investigation of 12 m.y. old volcanic rocks from the left-lateral shear zone of Lake Mead, Nevada, show that: (a) no significant structural tilt has occurred here, with difference between observed and expected inclination of only -0.8°; (b) the data indicate a significant counterclockwise rotation about a vertical axis of 27.1°. This rotation was accommodated by slip on a set of the NW right-lateral strike-slip faults, and implies WNW elongation by a factor of 1.33.

The results imply that the strike-slip faulting is the primary process for the accommodation of crustal deformation in the Lake Mead shear zone, and that it is normal faulting which is secondary. In view of similar bits of data from other parts of the Basin and Range, the results also strongly suggest that strike-slip faulting may have the same dominance in other parts of the Basin and Range Province.

-1777-

T11C-07 1030h

EVIDENCE OF ROTATION ABOUT A VERTICAL AXIS DURING EXTENSION AT YUCCA MOUNTAIN, SOUTHERN NEVADA

SCOTT, R. B., and ROSENBAUM, J. G. (U.S. Geological Survey, Box 25046, Federal Center, Denver, CO 80225)

Yucca Mountain (YM) consists of east-dipping structural blocks bounded by major west-dipping, high-angle normal faults that offset strata more than 100 m. In general, each block contains two zones: a western zone with gently dipping strata (5-20°) and few faults, and an eastern zone with steeper dipping strata and abundant west-dipping, high-angle, imbricate normal faults having less than 10 m of offset. From north to south over 25 km, imbricate faults increase in number, cumulative stratigraphic offset increases, eastward dips of strata increase about 20°, and dips of major normal faults decrease about 10°. Remanent declinations of the welded Tiva Canyon Member of the Paintbrush Tuff (13 Ma), corrected for structural tilt about horizontal axes, display progressively greater clockwise declinations from north to south. Relative to the northern end of YM, the southern end appears to be rotated clockwise 30° about a vertical axis. The strikes of major normal faults bounding the structural blocks have been rotated correspondingly. Both structural relations and the paleomagnetic data indicate increases in the degree of extension and vertical axis rotation toward the southern end of YM.

Regional tectonic framework and local structural geometry suggest that extension took place on detachment structures under YM. In 1985, Florian Maldonado reported that east-dipping Tertiary strata are truncated by flat-lying detachment faults above mylonitized gneiss in the Bullfrog Hills, 25 km west of YM. Upper plate Tertiary tuffs overlie lower plate Paleozoic rocks north of Bare Mountain 15 km to the west. Upper plate structures in these areas seem to be continuous with and similar to structures in Tertiary rocks at YM. The detachment structures under YM probably form surfaces on which the structural rotation took place as conceptually expressed by B. C. Burchfiel in 1965.

Chemical Evidence of Preferred Water Flow Paths in Unsaturated Fractured Tuffs, Yucca Mountain, Nevada

I. C. Yang[1]

Abstract

Pore fluids were extracted from cores of unsaturated tuff in a borehole from Yucca Mountain, Nevada, using triaxial compression and high-speed centrifugation methods. Chemical analyses for major cations and anions indicated no substantial difference in pore-fluids chemistry extracted by these two methods. The tritium log in the borehole indicated a tritium activity of about 20 Tritium Units[2] (T.U.) at a depth of 1 m; activity decreased to zero T.U. at 12 m, increased to 20 T.U. in the interval 35 to 45 m, and increased to 40 T.U. at ~~at~~ about 50 m. This profile inversion from 12 m to 50 m depth may indicate that water at 50 m did not percolate vertically from the alluvium directly above, but rather may indicate a rapid flow of recent water through fractures or non-vertical, high-angle to lateral flow paths or both. Such flow paths were predicted by Montazer and Wilson (1984)[3] in their conceptual model. This conclusion is further supported by major-ion concentrations of the pore fluids from this borehole which did not show progressive increases in concentrations with increasing depth in the upper 100 m. Assuming uniform mineral compositions of the tuff, longer water-rock contact time may result in larger concentrations. The smaller chemical concentrations in water at greater depth compared with larger concentrations at a shallower depth would indicate a relatively-fast travel time from non-vertical flow paths or a period of intense

recharge events at the site in the past. The large tritium concentration at deeper depth would be the result of fast travel time instead of the result of intense recharge in the past.

---

[1] U.S. Geological Survey, MS 421, Denver, Colorado 80225.

[2] 1 T.U. is equivalent to a concentration of 1 tritium atom in 10^{18} hydrogen atoms.

[3] Montazer, Parviz, and Wilson, W. E., 1984, Conceptual hydrologic model of flow in the unsaturated zone,Yucca Mountain, Nevada: Water-Resources Investigations Report 84-4345, 55p.

Department of Energy
Nevada Operations Office
P. O. Box 98518
Las Vegas, NV 89193-8518

FEB 0 5 1988

NNA.880208.0015

Ralph Stein, Director, Engineering and Geotechnology Division, Geologic Repositories HQ (RW-23) FORS

RESPONSE TO BROOKHAVEN NATIONAL LABORATORY (BNL) LETTER CONCERNING NEVADA NUCLEAR WASTE STORAGE INVESTIGATIONS (NNWSI) PROJECT LICENSING STRATEGY (REFERENCE WMPO ACTION ITEM #88-853)

Reference: Letter, Schweitzer to Stein, dtd. 11/6/87

This letter represents a restatement, incorporating wider project input, of our previously transmitted letter, WMPO:DEL-762, dated December 28, 1987, responding to the referenced BNL letter of November 6, 1987 (enclosure 1). The NNWSI Project technical staff continues to disagree with the rationale, interpretation, and logic of the BNL letter. These disagreements are outlined in Enclosure 2. Detailed reasons and explanations for NNWSI disagreement are discussed on a point-by-point basis in Enclosure 3.

The BNL letter is based upon what we feel is a limited and incomplete perspective concerning calcite and opaline silica deposits located along faults near Yucca Mountain and the potential for hydrothermal activity. The letter also contains statements indicating a lack of information and understanding on the part of BNL concerning the NNWSI Project licensing strategy. The NNWSI Project does not agree with the BNL recommendations as they are not based on complete information and current interpretations.

The Waste Management Project Office (WMPO) recommends that appropriate U.S. Department of Energy, WMPO and Headquarters staff meet in Las Vegas during March for collegial discussions to provide the appropriate BNL staff the opportunity to understand the NNWSI Project licensing strategy, project plans, and scientific information available to the project. At that time, the NNWSI Project will be pleased to respond to any constructive critiques and recommendations BNL should present, and incorporate those ideas into the project plans. Please contact either Donald E. Livingston, WMPO, FTS 575-8944, or U-Sun Park, Science Applications International Corporation, 702-733-9958, to make arrangements for this meeting. The NNWSI Project is fully confident that the present research plans and strategies are sound, technically feasible, and provide a high level of confidence in the licensing strategy.

Carl P. Gertz, Project Manager
Waste Management Project Office

WMPO:MBB-1106

Enclosures:
1. Ltr. 11/6/87 Schweitzer to Stein
2. Point-by-Point Outline Response
3. Response to Letter dated 11/6/87

cc w/o encls:
V. J. Cassella, HQ (RW-222) FORS

cc w/encls:
Steve Brocoum, HQ (RW-231) FORS
M. W. Frei, HQ (RW-231) FORS
Alan Berusch, HQ (RW-231) FORS
R. L. Bullock, F&S, Las Vegas, NV
J. C. Calovini, H&N, Las Vegas, NV
D. T. Oakley, LANL, Los Alamos, NM
D. T. Vaniman, LANL, Los Alamos, NM
L. D. Ramspott, LLNL, Livermore, CA
R. F. Pritchett, REECo, Las Vegas, NV
T. O. Hunter, SNL, 6310, Albuquerque, NM
S. R. Mattson, SAIC, Las Vegas, NV
U-Sun Park, SAIC, Las Vegas, NV
M. E. Spaeth, SAIC, Las Vegas, NV
M. D. Voegele, SAIC, Las Vegas, NV
E. P. Gausse, Weston, Washington, DC
Edward Benz, Weston, Washington, DC
R. E. Jackson, Weston, Washington, DC
D. L. Siefken, Weston, Washington, DC
John Stuckless, USGS, Denver, CO
L. R. Hayes, USGS, Denver, CO
M. B. Blanchard, WMPO, NV
James Blaylock, WMPO, NV
W. R. Dixon, WMPO, NV
M. P. Kunich, WMPO, NV
D. L. Livingston, WMPO, NV
L. P. Skousen, WMPO, NV
R. A. Levich, WMPO, NV
D. C. Dobson, WMPO, NV

Point by Point Outlined Response to the November 6, 1987 letter from D. G. Schweitzer to Ralph Stein

NNWSI Project Comment Number Found on Enclosure 1	Outlined Response
1	References that are cited in the November 6th letter do not represent a "significant quantity of independent and consistent information." References cited are used out of context and/or are administrative documents that do not reflect the scientific knowledge of the NNWSI Project. Further details are provided in Enclosure 3 (Section 2.1).
2	The central philosophy of the NNWSI licensing strategy is to rely on the engineered barrier system performance under the unsaturated site conditions. The site is expected to remain unsaturated for the next 10,000 years and no information has been presented in the November 6 letter which contradicts this central philosophy (see Section 4.1 in Enclosure 3).
3	This quotation is from an outdated draft document which does not represent the current NNWSI Project position. Licensing strategy that relies on a limited amount of water available to contact the waste package is only a partial component of the overall strategy. The NNWSI Project waste package compliance strategy also relies on other components such as the waste form, the waste container, and the engineered environment. Performance of these major components in turn is supported by many subcomponents including the spent fuel cladding, solubility limits, leach rate, thermal field, airgap in conjunction with high matric potential (i.e., water does not cross over the airgap between the waste package and the borehole due to capillary effect), etc. Therefore, the partial reliance in the waste package performance strategy of a limited amount of water is a technically defensible strategy with the current understanding of the site (see Section 4.2, in Enclosure 3).
4	The NNWSI Project has not been trying to identify the origin of these deposits since the early 1980's. Serious work and recognition of potential licensing implications was not recognized until 1985 at NNWSI Project staff

ENCLOSURE 2

4 Cont. initiation. It is not the strategy of the NNWSI Project to absolutely identify the origin of these deposits, but to learn if they have any significance at repository depths under anticipated conditions (see Comment 5). Further details are provided in Enclosure 3 (Sections 2.1 and 2.2).

5 It is not the purpose or strategy of the NNWSI Project to absolutely determine the origin of the calcite and opaline silica deposits. Although an understanding of the exact mode of origin would be beneficial, it is not necessary for licensing concerns. For licensing concerns a knowledge, within limits, of the nature and amounts of fluid involved for anticipated events is a major aspect of this concern. In addition, the recurrence interval of events, the age of the deposits, and the consequences of a particular origin on isolation and containment are important concerns in licensing strategy that the November 6 letter has not acknowledged. Further details are provided in Enclosure 3 (Sections 2.1 and 2.2).

6 See Comments 4 and 5 above. Only two origins are discussed in the November 6 letter, in contrast the NNWSI Project is considering several working hypotheses including: a pedogenic, hydrothermal, seismic pumping, cold spring, or combination of the above hypotheses. Further details are provided in Enclosure 3 (Sections 2.1 and 2.2).

7 It is not the intent of the NNWSI Project to center its research program on a "great deal of publicity." The NNWSI Project does not intend to base its licensing strategy on the amount of publicity a topic receives, but on careful technical data analysis and judgment. Further details can be found in Enclosure 3 (Section 5.0). In addition, the documents cited here are non-technical documents (e.g., Nevada Nuclear Waste News), administrative documents (e.g., GAO Reports), or out of date (e.g., NRC comments on the EAs).

8 As pointed out in the response to Comments 4 and 5, it is not necessary to absolutely identify the origin of the deposits in question. The November 6 letter overemphasizes the length of time under which these deposits have been under scrutiny and the licensing implications of these deposits. Detailed work, analysis, and publication may take up to 30 to 39 months, but the NNWSI Project believes the work can be accomplished in an earlier timeframe and that the work will resolve the issue or allow the Project to address any licensing concerns. Further details

8 Cont. concerning these comments can be found in Enclosure 3 (Section 2.1).

9 It is the opinion of the NNWSI Project that the November 6 letter was overstated and exaggerated the potential for hydrothermal activity. (Also see Enclosure 3 (Section 3.0) and responses to Comments 10 and 12). At the site, (1) the only known occurrence of hydrothermal activity is 11 million years old (low recurrence interval), (2) the present day down-hole temperatures are low, and (3) the calculated heat flows for Yucca Mountain are low, thus the potential for future hydrothermal activity is low (i.e., an unanticipated event).

10 It is not a correct statement that the consequences of the deposits in question as "originating through pedogenic processes have been mentioned only superficially in these workshops." The possible origins and licensing consequences have been discussed at great length by the Project. In addition, a pedogenic origin is the present USGS working hypothesis because all available data is consistent with this model (see Sections 2.1 and 2.3 of Enclosure 3).

11 This statement "substantial quantities of water may be involved" is misquoted. The statement was extracted from the February 28, 1986 workshop in which the possible regulatory implications of the deposits in question was presented to the investigators involved. It was not a statement of fact. (See Sections 2.1 and 2.2 of Enclosure 3).

12 Again the potential for hydrothermal activity is overstated and exaggerated (see Enclosure 3, Section 3.0 and responses to 9, 10). In addition, the statement on why the Wahmonie site was eliminated from consideration as a repository site is incorrect. The statement quoted is from the draft EA and does not appear in the final EA because of a lack of referenceable sources and the lack of scientific support. (See Section 3.2 in Enclosure 3).

13 The NNWSI Project is confident that it has acknowledged any areas of concern to its licensing strategy in the Consultation Draft SCP. Detailed and full analysis of the present data base on the calcite-silica deposits was not available at the time the Consultation Draft SCP was frozen. Further detailed study is planned by the Project (see Enclosure 3, Sections 2.2 and 3.2). Information that was available can

13 Cont. be found in Section 1.2.2.2.10 of the Consultation Draft SCP and further details are available from the workshops, peer review, and will become available in a NNWSI publication and in the Study Plans (Study 8.3.1.5.2.1, Characterization of Quaternary Regional Hydrology, Activity 8.3.1.5.2.1.5).

14 Regardless of the origin of the calcite and opaline-silica deposits located in the trench 14, based on presently available data, the site is expected to remain unsaturated for over 10,000 years. Any processes or events that will make the site saturated are unanticipated. Thus, under the expected unsaturated site conditions, the amount of water available to contact the waste package is very small, and the current waste package design basis is already conservative and is technically defensible. (See Section 4.2 in Enclosure 3).

15 No credible connection is made in the November 6 letter between the calcite and opaline silica deposits and the 10,000 year containment. 10 CFR 60.113 requires the waste package and the EBS to be designed for anticipated processes and events; and hydrothermal activity is not an anticipated process or event at the Yucca Mountain site based upon a considerable amount of data. Hence, the 10,000 year containment is neither required nor desirable (see Sections 3 and 4 in Enclosure 3).

16 See Point 3 above. In addition, the quoted "recent highly publicized events" has not changed any design basis for the EBS, nor affects the NNWSI licensing strategy. The Project does not intend to base its licensing strategy on the amount of publicity a topic receives, but on careful technical data analysis and judgment (see Section 4.2 in Enclosure 3).

Response To November 6, 1987, Letter
From Donald G. Schweitzer to Ralph Stein

1.0 Introduction

The NNWSI Project disagrees with the rationale, interpretation, and logic of the November 6th letter for reasons discussed in this enclosure. The analysis and conclusions reached in the November 6th letter are based on a misunderstanding of the current information, the use of existing information out of the context in which it was provided, the citation of administrative documents as scientific sources, and an unfamiliarity with a substantial body of literature that was not apparently considered in the analysis. The NNWSI Project is fully confident that our waste package licensing strategies, Site Characterization Plan (SCP), other plans, and research strategies are technically sound and lead to a total program that accounts for and has considered in depth the expressed concerns in the November 6th letter.

The following discussion is organized into this introduction, a point by point response to the statements made in the November 6th letter, and a summary. The response section responds to comments of the November 6th letter that are numbered on enclosure 1. Where appropriate, the responses include information concerning the Project's current status of activities, planned work, an historical perspective, and citation of references. In addition, the response section is structured on the topics discussed in the November 6th letter of increasing level of importance to the NNWSI Project licensing strategy. Thus, the response section sequentially addresses specific concerns centering around the (1) calcite and opaline silica deposits (hydrogenic deposits) located along faults in the area of Yucca Mountain, (2) the potential for hydrothermal activity at the Yucca Mountain site, and hence, (3) the waste package licensing strategy.

2.0 Calcite and Opaline Silica Deposits (Hydrogenic Deposits) Located Along Faults

2.1 Chronology of Events

The November 6th letter states (Comments 4, 5) "Ever since the early 1980's, NNWSI, DOE-WMPO, NRC, USGS, SAIC, Los Alamos, Sandia, State of Nevada representatives, and DOE Headquarters staff have been involved in trying to identify the origin of the calcite-silica deposits in a trench located between the east slope of Yucca Mountain and Exile Hill which cross-cuts the Bow Ridge fault."

Furthermore, it is stated (Comment 6) "From 1984 to the present, a series of workshops and reviews have not been able to determine whether the deposit was formed from surface water running down (pedogenic), or springwater ascending (hydrothermal)." These comments are discussed in this section and other sections.

ENCLOSURE 3

The chronology of events discussed above leading up to the Projects detailed analysis of concerns related to deposits located along faults is not correct and implies that the Project has not applied the appropriate level of detail or amount of analysis upon these concerns. We believe that the letter has considerably overstated the duration and intensity of studies (Comments 4, 5, 6, 8) concerning the calcite and opaline silica deposits located in trench 14. Initial mapping of the trench walls was indeed done in the early 1980's with the interpretation that the calcite and opaline silica represented accumulations in the near surface soil and rock from the infiltrating water. The first suggestion of other possible origins, including a hydrothermal origin, was made by NNWSI staff in September of 1984. The full extent of the deposits located in trench 14 along the Bow Ridge Fault was not known until 1985 when the trench was deepened because of this NNWSI Project staff initiation. The possible implications of these deposits were not fully developed until 1985 and, therefore, the debate on this trench has not been ongoing since the "early 1980's."

In 1985 the possible geologic implications of these deposits were discussed by a wide range of personnel possessing expertise in a variety of geologic specialties (Biddison, 1985), and it was determined that the Project would be best served by initiating a workshop with a wide range of experts to gauge and resolve the possible licensing implications. In February of 1986, a workshop was held (Voegele, 1986a) with over twenty technical participants to debate possible origins, present the available information, and begin to establish a program that would address the concerns which had been discussed. An additional workshop (Voegele, 1986b) was held in April of 1986, again with over twenty technical participants, to formalize the present knowledge, plan future research, and discuss the licensing implications.

As a result of these workshops, it was determined that plans developed to study the calcite and opaline silica deposits (hydrogenic deposits) should incorporate two fundamental guidelines (Voegele, 1986a, 1986b):

a) The NNWSI Project plans would give credence to all hypotheses (multiple hypotheses) relating to the origin of the trench 14 and similar deposits so as not to bias the outcome.

b) An external Peer Review Panel would be formed to critique the proposed plans and offer additional expertise.

Nuclear Regulatory Commission (NRC) comments on the final Environmental Assessment (EA) concerning the deposits of calcite and opaline silica were received in December of 1986 (Browning, 1986) after the NRC attendance at workshops. A formal proposal of work was drafted by the United States Geological Survey (USGS) and Los Alamos National Laboratory (LANL), and submitted for peer review in March, and forwarded to the Peer Review Panel in May (Blanchard, 1987a).

To ensure that the planned research would resolve our technical and licensing questions, an external Peer Review staffed by recognized experts of stature was held in May of 1987 upon completion of this technical proposal. Thus, the purpose of the Peer Review Panel meeting was not to identify "the source of the deposit" as implied in the November 6th letter (Comments 5, 6, 8).

Although an understanding of the exact mode of origin would be beneficial, it is not necessary for licensing concerns. The November 6th letter incorrectly places the emphasis on the origin of these deposits when for licensing arguments all that is required is a knowledge, within limits, of the nature and amounts of fluid involved in anticipated events. The Project is fully confident that limits on the nature and amounts of fluid involved for anticipated events can be bounded by the work being planned. This information can then be assessed in the waste package strategy which is considered to be conservative (See Section 4.0) and evaluated for other performance assessment concerns.

The Peer Review Panel made many recommendations (Hanson, 1987) to the Project, some of which are discussed in sections presented below. The earlier workshops and the Peer Review were conducted without bias toward any specific origin (Section 2.2.2). This has apparently led to the mistaken impression expressed in the November 6th letter (Comments 1, 13, 14) that the NNWSI Project has no clearly defined approaches to resolving regulatory questions with a high degree of confidence. The waste package strategy germane to the November 6th letter is discussed in Section 4.0. Finally, no new concerns or ideas on the implications of the calcite and opaline silica deposits (hydrogenic deposits) that have not been considered and evaluated by the Project in detail were raised by the November 6th letter.

The NNWSI Project does not agree that a significant quantity of information has been presented in this letter (Comment 1) which contradicts licensing strategy (see Sections 2.0, 3.0, and 4.0). The claim that the information presented in the letter is "independent and consistent" is unsubstantiated by the references cited in the letter (Comment 7). Use of the references in this letter has been selectively biased and does not take into account the chronology of events as described in this section. Furthermore, many of the references cited are non-technical or administrative documents. For example, this includes the Nevada Nuclear Waste Newsletters and GAO reports. As stated in the sections below, the NNWSI Project is confident about its present licensing strategy based upon the presently available scientific information.

2.2.1 Origin of Deposits

The November 6th letter implies that only two different origins are possible for calcite and opaline silica deposits (hydrogenic deposits) (Comment 4) when several different origins are being considered, and these include a pedogenic origin (downward flux of infiltrating water), a cold spring origin, a hydrothermal origin, a seismic pumping origin, and combinations of the above origins (Voegele, 1986 a,b). It should be recognized that determination of modes of origin does not necessarily yield information about potential conditions at repository depth. Conversely, other data concerning the deposits may yield information on conditions expected at repository depth without defining a unique origin. All possible origins were considered in the workshops (Voegele, 1986 a,b) and in the peer review (Blanchard, 1987a; Hanson, 1987). None of these origins or mechanisms are presently considered as anticipated events except the infiltration of surface water which may be concentrated along conduits (faults and fractures) (Consultation Draft SCP, 1988).

On page 2 of the November 6th letter (Comment 11) the quote "substantial quantities of water may be involved" extracted from the February 28, 1986 workshop (Voegele, 1986a) is misused in the context of the presentation made by Max Blanchard (DOE/WMPO). The presentation was intended to describe possible regulatory implications to the technical staff present if substantial quantities of water were involved (Voegele, 1986a). Thus, it has not "been recognized that even under the most favorable conditions of origin (i.e., surface water running down), "substantial quantities of water may be involved" (Comment 12). Further, as stated above, the volume of fluid per year is considered to be low and accounted for in our waste package licensing strategy (Section 4.0). A consideration of the volume of fluids involved is being planned (Section 2.1) (Blanchard, 1987a,b; Voegele, 1987c).

In addition, the calcite and opaline silica deposits (hydrogenic deposits) located in trench 14 occur in a valley that is over a kilometer away (Swadley and Hoover, 1983) from the proposed repository and may actually divert water away from the repository along this or other major faults which occur in valleys. Present waste package strategy is conservative enough that a pedogenic or seismic pumping mechanism can likely be accommodated (See Section 4.0) even under the unlikely condition that further information indicates they are anticipated events. A seismic pumping (water movement initiated from the water table as a result of faulting) or a pedogenic origin are not thought to represent a severe hazard to the functioning of a repository because such origins would involve a episodic, likely low-volume, and brief flux of water from depth or above, respectively. The banded nature of these deposits (Voegele, 1986a, 1986b; Blanchard, 1987a) is compatible with this conclusion. A cold spring origin is not an anticipated event because known spring activity in the area is believed to be Pliocene in age based upon their stratigraphic relationships (Swadley and Carr, 1987). Hydrothermal activity (Section 3.0) is not an anticipated event because the present thermal regime at Yucca Mountain is low, known hydrothermal events are old and likely related to 11 m.y. old volcanism, and thus, the expected recurrence intervals of hydrothermal activity are extremely long (Stuckless and Mattson, 1987).

Futhermore, the November 6th letter oversimplifies the possible origins (Comments 4, 10, 11, 14) of the deposits because several different depositional events are recognized in trench 14 including: (1) older depositional phases consisting of silica cemented breccia and druzy quartz emplacement are reasonably interpreted to be of hydrothermal origin or related to the original time period of deposition of the tuff units (See Section 3.0 for status of this origin) and (2) younger calcite and opaline silica veining common to faults in the Basin and Range for which a pedogenic origin has generally been assumed (Blanchard, 1987a; Hanson, 1987). To evaluate the different implications of these models, the Peer Review Panel recommended a sequence of studies to be performed with evaluation points to determine if further research was necessary. These studies were to consist initially of field mapping and detailed paragenesis and age determinations. Data related to these areas of study are available and are continuing. The Peer Review Panel recommended that "If the veins are young (ie., less than 100,000 years old), a more complete study, including mineralogy; fluid inclusions; major, minor, and trace element; tracer isotopes studies will be required. If the veins are old (i.e., greater than 100,000 years) and formed from cold waters, no further studies may be warranted."

Preliminary information presented at the Peer Review meeting (Voegele, 1987) is most consistent with a pedogenic origin of the vein deposits in trench 14 (see Comment 10), although other low temperature origins are being considered because of the preliminary nature of the data base. Information presented at the peer review indicates that these deposits were formed at temperatures less than 30 degrees celcius and that a preliminary radiometric age is greater than 350,000 years before present. The deposits age or the expected recurrence interval of the processes or events which lead to the deposition of the deposits are (1) likely of such length that their recurrence is unanticipated, or (2) that the deposits formed over such a long period of time that the amount of water involved per unit time would be very small. Ongoing activities will refine the temperatures of formation and clarify the geochronology of these deposits.

In addition, the Quaternary stratigraphy may place bounds on the age of the deposits because the deposits appear to be truncated by the overlying alluvium (Taylor and Huckins, 1986). If detailed studies confirm this or an older age, the deposits will have little or no bearing on expected future conditions regardless of origin. This fact has not been acknowledged by the November 6th letter (see Comments 9, 10, 11, 13, 14) which vastly overstates the technical concerns. Finally, the only substantiated direction of transport in these fault zones is in a downward direction based upon the presence of basaltic ash in the deposits that only could be present due to downward transport (Taylor and Huckins, 1986; Voegele, 1986b). A variety of technical information is planned to be obtained in the future will further illucidate questions concerning these deposits. This includes the study plans that are being prepared in accordance with the guidance of the Peer Review Panel (Study 8.3.1.5.2, Characterization Under Activity 8.3.1.5.2.1.5).

3.0 Hydrothermal Activity

3.1 Past and Present Thermal Regime at Yucca Mountain

The November 6th letter implies that the potential for future hydrothermal activity (Comments 6, 9, 10, 11) is a likely or anticipated event. Correctly, if hydrothermal activity was considered to be likely (see Comment 9) at the Yucca Mountain site, great concern would be present on the consequences of such activity, for example, to the waste package integrity, waste isolation, and the rock characteristics. However, the November 6th letter greatly exaggerates the potential for hydrothermal activity at the site and ignores a great body of data on: (1) what is presently known on the recurrence interval and stratigraphic location of past hydrothermal activity at the site, and (2) the present available information on the current thermal regime at Yucca Mountain (Sections 3.2 and 3.3).

The potential for hydrothermal activity at the site is not considered to be an anticipated event by the Project. Nor does the Project or the workshop participants consider that "the potential existence of hydrothermal activity is sufficiently serious so that the consequences of the deposit originating through pedogenic processes have been mentioned only superficially in these workshops" as is claimed (Comment 11) in the November 6th letter. In contrast, the origin of the vein calcite and opaline silica deposits (hydrogenic deposits) consistent with the present data is a pedogenic origin (Taylor and Schroba, 1986; Taylor and Huckins 1986; Hayes, 1986). In addition, the workshop meetings and numerous other meetings have discussed at great length what the potential impacts of the mechanism of formation of these deposits could have on licensing strategy.

3.2 Recurrence Interval and Stratigraphic Position of Past Hydrothermal Activity

Past hydrothermal activity is known to have occurred at the site approximately 11 million years ago (Bish and Semarge; 1986, Bish, 1987), closely associated in time with the known volcanism in the area and the deposition of the tuffs from which the proposed repository is planned to be excavated. The paleogeothermal signature of this hydrothermal event is found only at depth beneath Yucca Mountain (Bish, 1987). Temperatures of this hydrothermal event are estimated to have reached $275^{\circ} \pm 50^{\circ}$ celsius at depths below 3,000 ft. in the northern half of Yucca Mountain (Drillhole USW G-2) and only $100^{\circ} \pm 50^{\circ}$ celsius at the bottom of deep drillholes located in the southern half of Yucca Mountain (Drillhole USW G-1) (Bish, 1987). No other hydrothermal events have been identified at the Yucca Mountain site.

Silica cemented breccias located along faults in close proximity to Yucca Mountain may be of hydrothermal origin (see Section 2.2.2), but are older than the calcite and silica vein deposits (Hanson, 1987; Voegele, 1987) and likely associated with the only known hydrothermal event dated at 11 million years (Bish, 1987) described above. In addition, the silica cemented breccias are truncated by the younger calcite and opaline silica vein deposits located along the Bow Ridge Fault and occur in areas where no vein deposits are located in close proximity (Busted Butte) (Mattson, 1986). The Busted Butte silica cemented breccia occurrence is overlain by wind-blown material known to be older that 700,000 years before present (Mattson, 1986). The NNWSI Project intends to perform further research to constrain the age relationships of these potential hydrothermal deposits.

Given the great age of the hydrothermal event found at depth beneath Yucca Mountain and the likely great age of the potential event(s) associated with the deposition of the silica cemented breccias, the NNWSI Project does not perceive any anticipated hydrothermal events at the Yucca Mountain site. In addition, the present thermal regime at Yucca Mountain is known to be low, based upon heat flow data and downhole temperature measurements (see Section 3.3). Future hydrothermal activity is considered as an unanticipated event and thus, need not be considered in waste package design and strategy to comply with 10 CFR Part 60 as implied in the November 6th letter (Comment 12).

On page 2 of the November 6th letter (Comments 12, 13), it is stated that "I believe the DOE can do little in the geology-hydrology portions of the draft SCP other than explicit acknowledgement of the problem." This statement is supported by reference to the potential for hydrothermal activity. The NNWSI Project does not agree that it should consider hydrothermal activity an anticipated event. The Project is confident that adequate coverage of all anticipated events is present in the SCP. It is acknowledged that the present coverage in the SCP does not include all of the information available to the NNWSI Project because recent reports have only just become available and the finalization of the external Peer Review was only recently completed. In addition, to the fullest extent possible, the geologic and hydrologic implications of calcite and opaline silica deposits (Section 2.0) to potentially effect licensing strategy have been acknowledged and accounted for in our licensing strategy for the waste package (Section 4.0).

Also on page 2 (Comment 12) is the statement that the Wahmonie NTS site was eliminated because "local surface deposits from recent warm springs indicate upward seepage of groundwater, possibly from great depths." The above comments are not correct because of the following reasons: (1) the quotation is from the Draft EA, was not found to be supportable and thus withdrawn from the Final EA, and (2) the reason the Wahmonie site was withdrawn from consideration was because "the area is structurally complex and hydrothermally altered" and that the "subsurface is as complicated as the surface, and the possibility of finding a repository medium at depth is remote" (Twenhofel, 1979). Thus, it is erroneous to state that the Wahmonie site was eliminated because of the presence of recent warm springs and to use this statement or the Wahmonie site as a geologic analogue of Yucca Mountain.

3.3 Present Day Thermal Regime at Yucca Mountain

The present day thermal regime located at Yucca Mountain is low. Surface temperatures of springs in the area are all significantly less than 90° celsius (Benson et al., 1983; Benson and McKinley, 1985; Bell and Larson, 1982; Garside and Schilling, 1979; Trexler et al., 1979). In addition, downhole temperatures at Yucca Mountain range from 21° celsius at a depth of 102 meters to a maximum of 65° celsius at a depth of 1,006 meters (Sass et al., 1980). (It is normal to obtain higher temperatures at depth in drillholes.) Thus, present day temperatures of waters do not indicate any potential for hydrothermal activity.

The Yucca Mountain area lies on the southwest boundary of the Eureka Low, a zone of low heat flow with all measurements less than 1.5 Heat Flow Units (HFU) (Sass et al., 1971; Lachenbach and Sass, 1977). Average continental heat flow is 1.5 HFU (Sass et al., 1971) and Nevada's average heat flow is 2.0 HFU (Garside and Schilling, 1979). Heat flow at Yucca Mountain has been calculated to range from 1.1 to 1.3 HFU (Sass and Lachenbach, 1982), consistent with the area being located on the edge of the Eureka Low.

Given the low water temperatures measured at the site and the low heat flow calculated for the site, there is little present day potential for hydrothermal activity at the site. In addition, hydrothermal systems take a substantial time to develop and last for millions of years (Silberman, et al., 1985; Smith and Shaw, 1979). Thus, little potential exists for the development of a hydrothermal system at Yucca Mountain in the future, especially the next 10,000 years. Finally, the NNWSI Project believes it has adequately considered all concerns related to the potential for hydrothermal activity at the site and presently considers this potential not to reflect an anticipated event. It is the opinion of the NNWSI Project that the November 6th letter has overstated and exaggerated the potential for hydrothermal activity (Comments 6, 9, 11, 12) at the site and misrepresented the need to consider hydrothermal activity in the waste package design and strategy.

4.0 Waste Package Licensing Strategy

4.1 Chronology of Events Related to the "Central philosophy of the NNWSI licensing strategy". (Comment 2 of November 6th Letter)

The initial focus of the NNWSI Project in the late 1970's was to evaluate the suitability of placing a repository in the saturated zone beneath Yucca Mountain. However, the concept of storing waste in the unsaturated zone had been noted for nearly a decade (Winograd, 1972; Winograd, 1974). Later, Winograd (1981) summarized the advantages associated with thick unsaturated zones, with special reference to the Nevada Test Site. Roseboom (1983) expanded on the concept and proposed design features that could enhance the isolation potential of this environment. At Yucca Mountain, as an understanding of the hydrologic system began to develop, and as a result of the urging by various sectors of the scientific community, more careful consideration was given to the unsaturated zone. In 1982, investigative emphasis was shifted to the unsaturated zone. Therefore, the central philosophy of the NNWSI Project licensing strategy is to rely on the engineered barrier system performance under the unsaturated site conditions.

At the Yucca Mountain site, the unsaturated zone could be a natural barrier to radionuclide migration that would add to the barriers that exist in the saturated zone system. The first component of the unsaturated zone barrier is the very low flux of water that occurs at Yucca Mountain. Next, a sequence of nonwelded porous tuffs that overlies the Topopah Spring Member may provide a natural capillary barrier to retard the entrance of water into the fractured tuffs (Montazer and Wilson, 1984). The NNWSI Project technical staff is confident that this centralized philosophy for the waste package licensing strategy is sound and defensible.

4.2 The Two NNWSI Waste Package Quotations (Comment 3) and Anticipated Water Flux (Comments 14, 16)

The quotations were extracted out of context and out of order from the October 17, 1986 draft of the waste package strategy document (executive summary) presented to Headquarters for review on October 18, 1986. Since the October 18, 1986, review, the BNL has participated in the review of NNWSI Project waste package licensing strategy (February 2, April 4, June 15, July 8, 1987) as a part of the SCP. The quotations no longer represent the current NNWSI Project strategy. Even in the October 17, 1986, draft of the waste package strategy, the unsaturated nature of the repository (limited amount of water) was identified only as one element of the strategy. The other elements to which performance goals were assigned include the waste container, the waste form, and the engineered environment.

The current NNWSI Project waste package compliance strategy allocates performances to the three elements, mentioned above, based on our current understanding of the site. Where uncertainties exist, research and development of the waste package and site characterization is underway or is planned to reduce or eliminate them. Performance assessment may suggest a reallocation of performance to meet the NRC 10 CFR 60.113 requirements.

According to 10 CFR 60.113, the waste package must be designed for anticipated processes and events over the next 10,000 years. NRC staff analysis of 10 CFR Part 60 (NUREG-0804) defines the anticipated processes and events as "such processes or events would not be anticipated unless they were reasonably likely, assuming that processes operating in the geologic setting during the Quarternary period were to continue to operate but with the perturbation caused by the presence of emplaced waste superimposed thereon." All currently available data are interpreted to indicate that the repository environment will remain unsaturated for 10,000 years, and that it is not reasonably likely that the water flux will exceed the bounding values used in the NNWSI Project strategy.

The goals for the amount of water contacting the waste packages, i.e., 5 and 20 L/yr, are based on a conservative upper bound of current percolation rate through the repository horizon (i.e., 0.5 mm/yr) (Wilson, 1985) and a factor of additional conservatism. At the 0.5 mm/yr flux, 0.25 L/yr is approximately the annual quantity of water that would pass vertically through the projected area above the vertical emplacement borehole. Multiplying by a factor of 20 for conservatism yields an annual volume of 5 liters passing through that projected area. For the later time periods, an additional factor of four was added for conservatism, allowing some packages to be contacted by up to 20 liters of water per year. Models of origin for calcite and opaline-silica deposits that could become anticipated events (Section 2.0) are accounted for in this conservative analysis, in that the waste package goals are 80 times the estimated flux. It is important to note that the factor of 80 is based purely on conservatism; in fact, that large an increase in flux would result in saturation of the site. Any greater flux is neither considered reasonably likely nor credible and is not designed for.

4.3 10,000 Year Containment (Comment 15)

The NNWSI waste package design strategy is based upon the expectation that a limited amount of water will come into contact with the waste containers over the next 10,000 years, and is thus consistent with the present understanding of anticipated site conditions. Furthermore, it is not clear that the existence of any upward flow activity at the Bow Ridge Fault necessarily implies its long-term impact on the waste package as envisioned by the BNL. Indeed, such regional flow phenomena would only be consistent with a water table high enough to completely inundate the repository horizon and much of the current surface area, which is certainly not likely to occur within the next 10,000 years. Therefore, the connection of the proposed hydrothermal activity at the Bow Ridge Fault and the 10,000 year containment is totally illogical. Further, hydrothermal activity is not an anticipated event (See Section 3.0).

In addition, the NRC 10 CFR 60.113 states that the containment period shall be not less than 300 years nor more than 1,000 years after permanent closure of the geologic repository. A 10,000 year containment by the EBS will put an unnecessary burden on the EBS and is inconsistent with the NRC's multiple barrier approach. In explaining the concept of the multiple barrier, 10 CFR 60.102 states, "Following the containment period, special emphasis is placed upon the ability to achieve isolation of the wastes by virtue of the characteristics of the geologic repository." This is consistent with the NRC staff position (NUREG-0804) that the performance of the engineered and natural barriers must each make a definite contribution. The NRC 10 CFR 60.101(a)(2) also states; "While these performance objectives and criteria are generally stated in unqualified terms, it is not expected that complete assurance can be presented. A reasonable assurance...is the general standard that is required." In view of the fact that the NNWSI Project strategy is based on the current knowledge and anticipated behavior of the site, the 10,000 year containment that is recommended by the BNL is neither necessary nor beneficial and is totally inconsistent with 10 CFR Part 60.113. It should also be noted that in despite of their support for 10,000 year containment, BNL has never established a technically feasible design for a 1,000 year waste package containment, not to mention a waste package designed for 10,000 year containment.

5.0 Summary

The NNWSI Project has arduously and diligently centered its efforts toward a technically sound licensing strategy on concerns related to the presence of calcite and opaline-silica deposits (hydrogenic deposits), the potential for hydrothermal activity, and the waste package. Some minor problems may remain; however, the basic approaches have been repeatedly and thoroughly analyzed to an extent that the NNWSI Project is fully confident that the present licensing strategies, plans, and planned future research adequately address the concerns expressed in the November 6th letter and reflect a defensible position on the part of the NNWSI Project.

The NNWSI Project does not agree with the rationale, interpretation, and logic of the November 6th letter for the technical reasons briefly discussed above. The November 6th letter exhibits a misunderstanding of our current Project status, plans, and strategies. Finally, the November 6th letter clearly emphasizes that the Project should base its technical program on the level of publicity (Comments 7, 16) a topic receives. The Project does not intend to base its licensing strategy on the amount of publicity a topic receives, but on careful technical data analysis and judgement. Much of the technical information available to the NNWSI Project has not been cited and apparently reflects that BNL is unaware of a substantial body of technical documents. It is our recommendation that the appropriate staff from BNL amiably meet in Las Vegas during March with technical, WMPO/DOE and DOE/HQ staff. The meeting in Las Vegas will provide the opportunity for the BNL staff to understand the NNWSI Project licensing strategy, Project plans, and become familiar with the scientific information available to the Project. Please contact either Donald Livingston, WMPO (FTS 575-8944) or U-Sun Park, SAIC (702-733-9958) to make arrangements for this meeting.

6.0 References

Bell, E. J., and L. T. Larson, 1982. Overview of Energy and Mineral Resources for the Nevada Nuclear Waste Storage Investigations, Nevada Test Site, Nye County, Nevada, NVO-250, Nevada Operations Office, U.S. Department of Energy, Las Vegas.

Benson, L. V., and P. W. McKinley, 1985. Chemical Composition of Ground Water in the Yucca Mountain Area, Nevada, 1971-84, USGS-OFR-85-484, Open-File Report, U.S. Geological Survey, Denver, Colo.

Benson, L. V., J. H. Robison, R. K. Blankennagel, and A. E. Ogard, 1983. Chemical Composition of Ground Water and the Locations of Permeable Zones in the Yucca Mountain Area, Nevada, USGS-OFR-83-854, Open-File Report, U.S. Geological Survey, Denver, Colo.

Biddison, C. L., to D. B. Jorgenson, 1985. Calcite/Silica Field Workshop - November 5-6, 1985, L85-TPD-CLB-116.

Bish, D. L., 1987. Evaluation of Past and Future Alterations in Tuff at Yucca Mountain, Nevada Based on the Clay Mineralogy of Drill Cores USW G-1, G-2, and G-3, LA-10667-MS, Los Alamos National Laboratory, Los Alamos, N.Mex.

Bish, D. L. and R. E. Semarge, 1982. "Mineralogic Variations in a Silicic Tuff Sequence: Evidence for Diagenetic and Hydrothermal Reactions," abstract of presentation at the 19th Annual Clay Minerals Society Meeting, Hilo, Hawaii, August 8-14, 1982.

Blanchard, M. B., to Peer Review Panel, 1987a. Peer Review on Deposits of Calcite and Opaline Silica Located Along Faults Near Yucca Mountain, Letter, WMPO:MBB-1085.

Blanchard, M. B., 1987b. Final Summary Report on the Calcite and Opaline Silica Deposits Peer Review, WMPO:DEL-401.

Browning, R. E., to S. H. Kale, 1986. NRC Staff Comments on the Final Environmental Assessments, December 22, 1986.

Draft SCP, 1988, Consultation Draft, Planned to be issued in January, 1988.

Garside, L. J., and J. H. Schilling, 1979. Thermal Waters of Nevada, Nevada Bureau of Mines & Geology Bulletin 91, University of Nevada, Reno.

Hanson, G. N., to M. B. Blanchard, 1987. Report of the Peer Review Panel on the Calcite and Opaline-Silica Deposits in the Yucca Mountain Area Nevada, June 19, 1987.

Hayes, L. R., to D. L. Vieth, 1986. Calcite-Silica Deposits, USGS Letter, December 29, 1986.

Lachenbruch, A. H., and J. H. Sass, 1977. "Heat Flow in the United States and the Thermal Regime of the Crust," The Earth's Crust, Its Nature and Physical Properties, J. G. Heacock (ed.), American Geophysical Union Monograph 20, pp. 626-675.

Mattson, S. R., to D. B. Jorgenson, 1986. Calcite-Silica Deposits near Yucca Mountain: The Silica Cemented Breccias, M86-GEO-SRM-311.

Montazer, P., and V. E. Wilson, 1984. "Conceptual Hydrologic Model of Flow in the Unsaturated Zone, Yucca Mountain, Nevada, U.S. Geological Survey, Water-Resources Investigations Report 84-4345.

NUREG-0804. "Staff Analysis of Public Comments on Proposed Rule 10 CFR Part 60, "Disposal of High-Level Radioactive Wastes in Geologic Repositories," U.S. NRC, 1983.

Roseboom, E. H., 1983. "Disposal of High-Level Nuclear Waste above the Water Table in Arid Regions," U.S. Geological Survey Circular 903, 21 p.

Sass, J. H., and A. H. Lachenbruch, 1982. Preliminary Interpretation of Thermal Data from the Nevada Test Site, USGS-OFR-82-973, Open-File Report, U.S. Geological Survey, Denver, Colo.

Sass, J. H., A. H. Lachenbruch, R. J. Munroe, G. W. Greene, and T. H. Moses, Jr., 1971. "Heat Flow in the Western United States," Journal of Geophysical Research, Vol. 76, No. 26, pp. 6376-6413.

Sass, J. H., A. H. Lachenbruch, and C. W. Mase, 1980. Analysis of Thermal Data from Drill Holes UE24a-3 and UE25a-1, Calico Hills and Yucca Mountain, Nevada Test Site, USGS-OFR-80-826, Open-File Report, U.S. Geological Survey.

Silberman, M. L., J. H. Stewart, and E. H. McKee, 1976. "Igneous Activity, Tectonics, and Hydrothermal Precious-Metal Mineralization in the Great Basin during Cenozoic Time," Society of Mining Engineers, Vol. 260, American Institute of Mining Engineers, pp. 253-263.

Smith R. L., and H. R. Shave, 1979. "Igneous-Related Geothermal Systems in Assessment of Geothermal Resources of the United States - 1978, L. J. P. Muffler (ed.)," Geological Survey Circular 179, 163 p.

Stuckless, J., and S. Mattson, 1987. "Potential for Hydrothermal Activity," in NNWSI Project Briefing for the ACRS Subcommittee on Waste Management, July 29, 1987, (DOE/WMPO).

Swadley, W. C., and D. L. Hoover, 1983. "Geology of Faults Exposed in Trenches in Crater Flat, Nye County, Nevada," USGS-OFR-83-608, 15 p.

Swadley, W. C., and W. J. Carr, 1987. "Geology Map of the Quaternary and Tertiary Deposits of the Big Dune Quadrangle, Nye County, Nevada, and Inyo County, California," USGS Miscellaneous Investigations Series Map I-1767.

Taylor, E. M., and H. E. Huckins, 1986. "Carbonate and Opaline Silica Fault-Filling on the Bow Ridge Fault, Yucca Mountain, Nevada-Deposition from Pedogenic Processes or Upwelling Ground Water?" Geological Society of America Abstracts with Programs, Vol. 18, No. 5, p. 418.

Taylor, E. M., and R. R. Schroba, 1986. "Morphology of Secondary Carbonate and Opaline Silica in Soils of Different Ages at the Nevada Test Site, Nye County, Nevada," Geological Society of America Abstracts with Programs, Vol. 18, No. 6, p. 769.

Twenhofel, W. S. to R. M. Melson, 1979. Summary of Essential Conclusions on Recommendations for Further Work in the Southwest Quadrandge of Nevada (Interpretative Title) April 24, 1979.

Trexler, D. T., T. Flynn, and B. A. Koenig, 1979. Assessment of Low-to-Moderate Temperature Geothermal Resources of Nevada, Final Report for the Period April 1978-June 1979, NVO/01556-1, Nevada Bureau of Mines & Geology, University of Nevada, Reno.

Voegele, M. D. to M. B. Blanchard, 1986a. Final Summary of Workshop on Calcite-Silica Deposits Near Yucca Mountain Held on February 28, 1986, L86-TPD-SM-81.

Voegele, M. D., to M. B. Blanchard, 1986b. Summary of Workshop on Calcite-Silica Deposits Near Yucca Mountain Held on April 28, 1986, L86-TPO-SRM-93.

Voegele, M. D., to M. B. Blanchard, 1987c. Final Meeting Minutes on the Calcite and Opaline Silica Peer Review, May 27-29, 1987, L87-SMI-SRM-224.

Wilson, W. W., to D. L. Vieth, 1985. Unsaturated Zone [illegible] December 24, 1985.

Winograd, I. J., 1972. "Near Surface Storage of Solidified High-Level Radioactive Waste in Thick (400-2,000 ft) Unsaturated Zones in the Southwest," Geological Society of America Abstracts with Programs, Vol. 4, No. 7, pp. 708-709.

Winograd, I. J., 1974. "Radioactive Waste Storage in the Arid Zone," Transactions of the American Geophysical Union, EOS, Vol. 55, No. 10, pp. 884-894.

Winograd, I. J., 1981. "Radioactive Waste Disposal in Thick Unsaturated Zones," Science, Vol. 212, No. 4502, pp. 1457-1464.

10 CFR Part 60 (Code of Federal Regulations), 1987. Title 10, "Energy," Part 60, "Disposal of High-Level Radioactive Wastes in Geologic Repositories," U.S. Government Printing Office, Washington, D.C.

ENCLOSURE 2

B. M. Crowe, Los Alamos National Laboratory, memo to D. Vieth, DOE Waste Management Project Office, 2/6/87, regarding the recency of activity at the Lathrop Wells volcanic center.

Craig, R. G., with contributions from B. L. Roberts and M. Singer, 1984. Climates and Lakes of the Death Valley Drainage System During the Last Glacial Maximum. Unpublished paper, available from the Department of Geology, Kent State University, Kent, Ohio.

Sass, J. H., and A. H. Lachenbruch, 1982. Preliminary Interpretation of Thermal Data from the Nevada Test Site, USGS-OFR-82-973, Open-File Report, U.S. Geological Survey.

Scott, R. B., and J. W. Whitney, 1987. The Upper Crustal Detachment System at Yucca Mountain, SW Nevada [abs.], Geological Society of America, Abstracts with Programs, p. 332-333.

Scott, R. B., and J. G. Rosenbaum, 1986. Evidence of Rotation about a Vertical Axis during Extension at Yucca Mountain, Southern Nevada [abs.], Transactions, American Geophysical Union, EOS, Vol. 67, No. 16, p. 358.

Sinnock, S., and R. G. Easterling, 1983. Empirically Determined Uncertainty in Potassium Argon Ages for Plio-Pleistocene Basalts From Crater Flat, Nye County, Nevada, SAND82-2441, Sandia National Laboratories, Albuquerque, New Mexico, pp. 1-31.

Stock, J. M., J. H. Healy, S. H. Hickman, and M. D. Zoback, 1985. Hydraulic Fracturing Stress Measurements at Yucca Mountain, Nevada, and Relationship to the Regional Stress Field, Journal of Geophysical Research, Vol. 90, No. B10, pp. 8691-8706.

Szabo, B. J., W. J. Carr, and W. C. Gottschall, 1981. Uranium Thorium Dating of Quaternary Carbonate Accumulations in the Nevada Test Site Region, Southern Nevada, USGS-OFR-81-119, Open-File Report, U.S. Geological Survey, Denver, Colo.

Szabo, B. J., 1984. Uranium-Series Dating of Fault-Related Fracture- and Cavity-Filling Calcite and Opal in Drill Cores from Yucca Mountain, Southern Nevada [abs.], Geological Society of America, Abstracts with Programs, Annual Meeting, Reno, NV., November 5-8, 1984, Vol. 16, No. 6, pp. 672-673.

Szabo, B. J., and T. K. Kyser, 1985. Uranium, Thorium Isotopic Analyses and Uranium Series Ages of Calcite and Opal, and Stable Isotopic Compositions of Calcite from Drill Cores UE25a 1, USW G-2, and USW G-3/GU-3, Yucca Mountain, Nevada, USGS-OFR-85-224, Open-File Report, U.S. Geological Survey, Denver, Colo.

Tyler, S. W., 1987. Review of Soil Moisture Flux Studies At the Nevada Test Site Nye County, Nevada, Desert Research Institute, Water Resources Publication #45058, 48 p.
(Recently published document, not funded through repository program)

Wells, S. G., L. D. MacFadden, C. Renault, B. D. Turrin, and B. M. Crowe (1988) A Geomorphic Assessment of Quaternary Volcanism in the Yucca Mountain Area, Nevada Test Site, Southern Nevada [abs.] Geological Society of America, Abstracts with Programs, Coridilleran Section, Vol. 20, #3, p. 242.

Whitney, J. W., R. R. Shroba, F. W. Simonds, and S. T. Harding, 1986. Recurrent Quaternary Movement on the Windy Wash Fault, Nye County, Nevada [abs.], Geological Society of America, Abstracts with Programs, p. 787.

Yang, I. C., 1988. "Chemical Evidence of Preferred Water Flow Paths in Unsaturated Fractured Tuffs, Yucca Mountain, Nevada [abs.]
(Abstract is currently under review at DOE-Waste Management Project Office.)

SAIC/T & MSS
RECEIVED
FEB 19 1987
FILE NO. ______
REF. NO. 12402

Los Alamos
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

memorandum

NNA.870515.0061

TO: Don Vieth, WMPO

DATE: February 6, 1987

THRU: Don Oakley, N-5, MS F619

MAIL STOP/TELEPHONE: J514/7-3965

FROM: B. Crowe, INC-7 B. Crowe

SYMBOL: TWS-INC7-2/87-04

SUBJECT: RESULTS OF FIELD TRIP AND MEETING ON THE AGE OF THE LATHROP WELLS VOLCANIC CENTER

Participants from the Los Alamos National Laboratory, the U.S. Geological Survey, the University of New Mexico, WMPO, and SAIC reviewed field and laboratory evidence concerning the age of volcanic activity at Lathrop Wells volcanic center. We examined critical field relations at the volcanic center on February 3, 1987. On February 4, 1987, we reviewed the scientific and programmatic implications of this evidence at a meeting in the SAIC office in Las Vegas. We additionally discussed areas of future research that are needed for the volcanism studies part of the Site Characterization program. The following are major conclusions from the field trip and meeting and represent the consensus opinions of the participants.

1. We agreed that multiple lines of evidence support the observation that there were multiple eruptive events separated by a significant time gap at the Lathrop Wells volcanic center. This evidence includes:

   A. Field observations suggest the lava flows of the center were erupted from a north-northwest-trending fissure system. They were not erupted from the main scoria cone of the Lathrop Wells center.

   B. K-Ar determinations indicate the age of the lavas are about 150,000 ± 100,000 yrs old (2 sigma).

   C. Cone degradation parameters suggest the main scoria cone of the Lathrop Wells center is significantly younger than both the lava flows and the scoria cone/fissure system that was the source of the lava flows.

   D. The presence of angular, Ti-Cr bearing magnetite crystals in varnish developed on the 150,000 yr old lavas requires introduction of the crystals from a separate and younger eruption. The most likely source of these crystals was the eruptions that produced the main scoria cone of the Lathrop Wells center.

2. The exact age of the youngest volcanic event at the Lathrop Wells center (formation of the main scoria cone) is not yet well constrained. It is significantly less than the age of the lava flows (150,000 yrs old) and is possibly younger than 20,000 yrs. This is based on calibration of cone degradation parameters extrapolated from geologic research

in the Cima volcanic field. the surface position and angular crystal form of Ti-Cr-bearing magnetite crystals in varnish developed on 150.000 yr old lavas. and the estimated time required for development of soils on the cone slopes. Cone degradation parameters of the main scoria cone best match a 15.000 yr old scoria cone in the Cima volcanic field (see information in Dohrenwend and others. 1986. Geologic Society of America Bulletin. Spring 1986). This suggested age range is much younger than the previously documented age estimate of the center of about 270.000 yrs. This new information will require reexamination of volcanic rate parameters for calculation of the probability of volcanic disruption of a repository. The new data point (age and magmatic volume) plot on the previously established regression line. However. new approaches to calculating a rate of magma generation and predicting the time and volume of the next volcanic event are suggested by a curve fit of cumulative volume versus time for all volcanic activity of 4 m.y. and younger in the Yucca Mountain region. Additionally we will have to reevaluate the ash horizons in the trenches used for neotectonic studies to test whether any of the ashes could correlate with the newly recognized young volcanic event.

3. Important data that may provide more precise constraints on the age of the Lathrop Wells cone is currently in jeopardy from commercial quarrying of cinder. If quarrying continues. this information could be permanently lost. Significant outcrops of scoria have already been removed in the last year. Field investigations will need to be conducted concurrently with cinder quarrying to avoid loss of data.

Our discussions of future research needs for the volcanism studies were reviewed with SAIC on February 5. 1987 and incorporated into Chapter 8.3 of the SCP. We will also include the information in the Study Plans in support of the SCP and in the FY88 and FY89 work plans for the volcanism work breakdown task. I have attached a list of suggested required studies to resolve the current age problems with the youngest volcanic event. All are consistent with previously proposed studies. Two studies will require some expanded work including: 1) evaluation of the age of the youngest volcanic event using experimental isotopic and varnish techniques and 2) development of new techniques for correlation of ash horizons in trenches with established volcanic events.

List of Participants

Bruce Crowe	LANL. Los Alamos
Gary Dixon	USGS. Las Vegas
Dean Eppler	SAIC
Ken Fox. Jr.	USGS. Denver
Charles Harrington	LANL. Los Alamos
Donald Livingston	DOE/NV/WMPO
Steve Mattson	SAIC
Martha Pendleton	SAIC
Frank Perry	LANL. Los Alamos
Ralph Shroba	USGS. Denver
W. C. Swadley	USGS. Denver
Brent Turrin	USGS. Menlo Park
Stephen Wells	UNM. Albuquerque
John Whitney	USGS. Denver
Jim Yount	USGS. Menlo Park

REQUIRED STUDIES FOR REFINING VOLCANIC CHRONOLOGY

TOPIC	COVERED IN SCP: CHP 8.3
1. Detailed field mapping of Lathrop Wells volcanic center using 1:5000 scale color photography and oblique photography of cinder quarry walls.	YES
2. Investigate obtaining historic photographs of Lathrop Wells volcanic center to evaluate geologic information prior to quarrying operations (assign responsibility to SAIC).	NO
3. Quarry mapping for tephrachronology and analysis of soil stratigraphy of the Lathrop Wells scoria cone and adjacent areas. May require small trenches in selected outcrop areas.	YES
4. Geochemistry of scoria sequences for young volcanic centers and ash horizons in trenches. Information will be used for geochemistry parts of the volcanic hazards studies and for correlation of ash horizons with volcanic events.	YES
5. Development of calibration curves for the Yucca Mountain area for cone degradation parameters. Analysis of soil development and soil stratigraphy for young volcanic centers in the Yucca Mountain region. These techniques can be used to refine and cross-check volcanic geochronology.	YES
6. Continued dating of young volcanic rocks using the K-Ar technique.	YES
7. Experimental techniques for determining the age of volcanic rocks or the time of surface exposure of volcanic rocks. The preferred techniques include ^{36}Cl, ^{3}He, cation-dating of varnish, radiocarbon dating of varnish, U-Th disequilibrium and measurement of magnetic pole positions.	YES

BC:kc

Distribution:
TWS File
Gary Dixon, USGS, Las Vegas
Dean Eppler, SAIC
Ken Fox, Jr., USGS, Denver
Charles Harrington, LANL, Los Alamos
Donald Livingston, DOE/NV/WMPO
Steve Mattson, SAIC
Martha Pendleton, SAIC
Frank Perry, LANL, Los Alamos
Ralph Shroba, USGS, Denver
W. C. Swadley, USGS, Denver
Brent Turrin, USGS, Menlo Park
Stephen Wells, UNM, Albuquerque
John Whitney, USGS, Denver
Jim Yount, USGS, Menlo Park
Max Blanchard, DOE/NV/WMPO